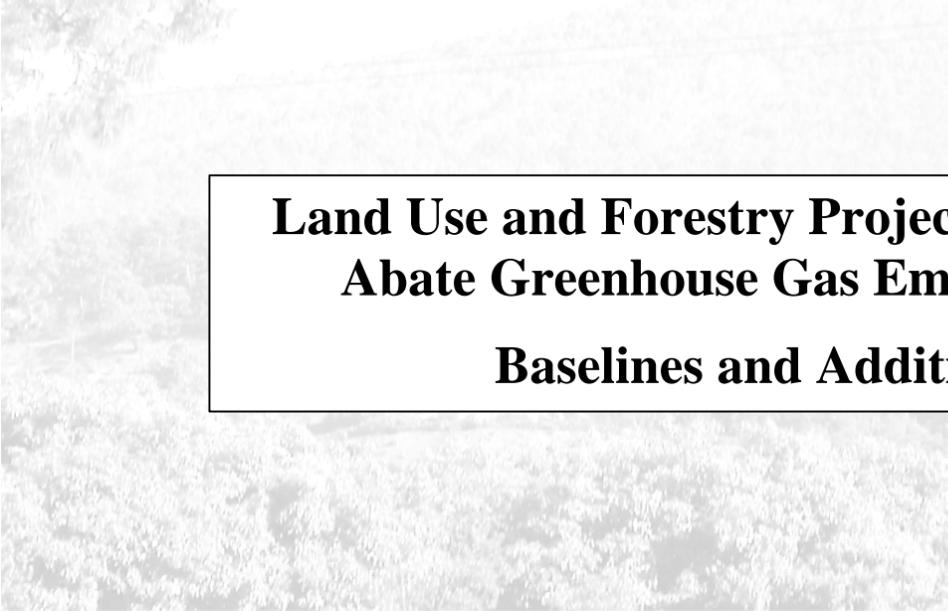Final Report on Phase 2

Land Use and Forestry Projects That Abate Greenhouse Gas Emissions: Baselines and Additionality

April 2002

Land Use and Forestry Projects That Abate Greenhouse Gas Emissions:

Baselines and Additionality

Final Report on Phase 2

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Executive Summary

A fundamental, and challenging, component of land use, land-use change, and forestry (LULUCF) projects is the determination of the extent to which project interventions lead to greenhouse gas (GHG) benefits that are "additional" to business-as-usual or baseline scenarios. The focus of the overall project will be on developing approaches for generating baseline scenarios that project the change in the use of the land. To ensure their broad applicability and adoption by actual projects, the baselines will be developed from data aggregated in a "top-down" approach on a regional scale for two regions of Mexico—Calakmul and Meseta Purepecha regions.

Developing project-by-project baselines makes less sense in this field as it tends to make investment costs high, and tends to lead to baselines being developed by project developers and thus may be less credible. Development of regional baselines by project type would incur less investment cost, could provide opportunity for the respective country or state governments to decide on the type of projects they feel would lead to sustainable development, and is likely to result in more credible baselines. The question then becomes—which method should be used to develop such regional baselines? In this project we develop and test three methods that could be used for baseline development—the methods range from relatively simple model extrapolations of past trends in land use based on simple drivers such as population growth, to more complex extrapolations of past trends using spatially-specific models of land-use change driven by bio-physical and socioeconomic factors. The three approaches for developing baselines for changes in use of the land have been identified. The approaches use models, of varying complexities that provide a conceptual basis for integrating diverse measures into a self-consistent framework and for making meaningful extrapolations across time and space. All models will be used to project the baseline for typical project durations of at least 30 years.

In this interim report we report on the completion of work for phase 2: a description of the models, what data are needed for each model by region, and a description of the data acquired with examples.

We present the details of the three models (LUCS, GEOMOD2, and Deforestation model) and identified and acquired (still waiting for delivery of some items) a rich data set needed to simulate them and develop the baselines. The spatial and socio-economic data base is the most complete and will be available for simulating scenarios of land-use change. The carbon density data of land-use/land-cover classes are less complete, particularly of some converted land uses (such as avocado plantations); however the vast experience by the team in measuring carbon in the landscape and the available methods does provide us with the tools necessary to accomplish this task of estimating carbon densities. This rich data base will prove to be valuable not only for this project, but for other projects related to land use issues in the same regions of Mexico.

1.   Introduction

Activities that improve the way people use land offer significant potential for mitigating GHG emissions, thereby reducing the potential impacts of climate change. A fundamental, and challenging, component of land use, land-use change, and forestry (LULUCF) projects is the determination of the extent to which project interventions lead to greenhouse gas (GHG) benefits that are "additional" to *business as usual*. This is a key step in the development of LULUCF projects to ensure accurate crediting of their carbon impacts. Determination of "additionality" requires projection of realistic without-project baselines against which actual changes in carbon stocks resulting from project activities can be compared.

Development of credible project baselines is a key financial constraint to initiating land-use change and forestry projects to mitigate climate change. There are currently no standard practices for developing baselines and thus determining carbon additionality. Without tested and credible methods for developing baselines, the design and implementation of LULUCF projects is likely to be hampered. Here we report on work that seeks to develop various without-project scenarios at two areas in Mexico using different methods as a first and innovative step towards determining the most useful and effective method for developing baselines. The focus of the project will be on developing approaches for predicting the change in the use of the land, and to ensure their broad applicability and adoption by actual projects, the baselines will be developed from data aggregated in a "top-down" approach on a regional scale.

Three approaches for developing baselines for changes in use of the land have been identified. The approaches use models, of varying complexities, which provide a conceptual basis for integrating diverse measures into a self-consistent framework and for making meaningful extrapolations across time and space. All models will be used to project the baseline for typical project durations of at least 30 years.

Two project areas were selected for the study based on a set of criteria, including: identification of suitable project area and activities, likelihood that they will meet the additionality test, availability of relevant data, and local expertise on the technical issues involved in project design. The results of this task were the selection of two sites based on an evaluation of pertinent criteria: Calakmul area in Campeche and Meseta Purepecha region in Michoacan.

One outcome of the work to date is that discussions among the team see that the way forward in the implementation of LULUCF projects is the need for the development of regional baselines. Developing project-by-project baselines makes less sense in this field as it tends to make investment costs high, and tends to lead to baselines being developed by project developers and thus may be less credible. Development of regional baselines by project type would incur less investment cost, could provide opportunity for the respective country or state governments to decide on the type of projects they feel would lead to sustainable development, and is likely to result in more credible baselines. The question then becomes—which method should be used to develop such regional baselines? As mentioned above, here we develop and test three methods that could be used for baseline development—the methods range from relatively simple model extrapolations of past trends in land use based on simple drivers such as population growth, to

more complex extrapolations of past trends using spatially-specific models of land-use change driven by bio-physical and socioeconomic factors.

All these models require data to varying degrees: from less data intensive for the simple model of deforestation versus population, to highly data intensive for the spatial modeling. The project goals will be achieved in three phases: (1) identification of the study regions, identification of cooperators, organizational meeting, and capacity building workshop with collaborators; (2) description of the models and their respective data needs and acquisition of the data; and (3) simulations of the models and development of the baselines, development of criteria for evaluating the models, and a comparison of the approaches. Here we report on the completion of work for phase 2: a basic description of the models, what data are needed for each model by region, and description of the data acquired with examples.

2. Objectives of Phase 2 of the Project

This project seeks to address the data gaps associated with the development of baselines and the determination of additionality. The specific goals of phase 2 are:

A) Identify data needs and sources of data for both sites for all three models

B) Prepare a list of data needs and sources, identifying any gaps and outlining a strategy for acquiring needed data.

C) Acquire needed data for simulating the three model for both sites.

D) Prepare a report that includes a description of the models, the data required, and a summary of the data acquired.

3. Data Needs and Data Acquired by Model Type for Each Region

In this section we present the data acquired to complete the development of the baselines for each site. As will be seen below we have acquired a very rich data base for the two regions that will prove to be valuable not only for this project, but for other projects related to land use issues. At the end of this work we will put all data acquired onto CDs for distribution to all our collaborators/cooperators.

3.1   The LUCS Model

Although the team has experience with this model, it was felt that it needed re-evaluating for this study Based on our experience using LUCS (Land Use and Carbon Sequestration model) and the contributions of some other users and carbon model developers, we identified a first set of changes to improve LUCS model. The first beneficial changes identified can be summarized in five groups.

- Printing/displaying options

- Updating Vensim version

- Adjustments for starting calculations

- Avoiding errors for future biomass calculations

- Improving model's structure to make it more suitable for regional estimates.

Further details of each of these five groups are given below:

a) *Closed Forest*

LUCS is restricted to only one Natural Forest vegetation type (or an average of different types) with a unique management/harvesting/growing dynamics. This makes the model less suitable for regional estimates where variation of carbon stocks and dynamics may occur. Thus, it would be useful to include an option to work with more than one natural vegetation type (maybe CF Type I, CF Type II, etc.).

b) *Grazed-Degraded Land*

- In many tropical areas, grazed land behaves like shifting agriculture. That is, in fallow/productive cycling periods which -in most cases- differ from those for agriculture. Carbon content thus varies from grazed to fallow categories.

- Another important issue is that frequently grazed land is also more profitable (commercially productive), thus pressuring land use change to a higher extent than agriculture.

- It would be then useful to add one more land use category (grazed land separated from degraded) which may convert to forest fallow and then back, representing also an important different source of income to farmers.

c) *Close Forest Biomass*

This variable is calculated by LUCS itself and it is supposed to represent the average biomass (tons per hectare) of the total closed forest area. However, it actually represents only the biomass of the initial (the original) closed forest. In other words, to calculate the average, LUCS does not consider the biomass of "new" closed forest areas that were once in a different land use category (such as forest fallow 3 or open forest) and were converted later to closed forest.

In many cases the sum of Closed Forest cat 1+ Closed Forest cat 2+ Closed Forest cat 3 areas is not equal to Total Close Forest area.

d) *Printing/displaying options*

- It is not useful to print a table with intervals of 0.25 years. For a 40-year time horizon project, for instance, you get 120 numbers just for one variable. I'm not sure if this is related with a parameter named "TIME STEP" (which value is constant and equals .25) but if this is true and this parameter could be changed, it would help.

- There is no possibility to copy and paste any number or graph in LUCS to compensate for the lack mentioned above.

- Graphs cannot be sized.

- There is no chance to see the differences (changing in variables) between more than 2 scenarios.

- For the Spanish version, translation is not complete. Sometimes you have messages in English and sometimes in Spanish (or mixed).

- To see the results of any small change made to one variable, users have to:

  1. Close the particular screen where they made changes

  2. Run (save) the scenario (with the same or new name)

  3. Go to Main Menu

  4. Open the scenario analysis screen

  5. Click on the "Select a variable" option

  6. Select the variable from the list

  7. Choose tabular or graphic form

8. See the results

If the results are not as expected and the user wants to change the same or other variable, then the following steps are needed:

9. Go to analysis scenario screen

10. Go to Main Menu

11. Go to Set Scenario Parameters

12. Choose the screen where changes will be made

13. Change the variable value

Go through the 8 first steps again.

(A shorter path and one that allows the user not to save the new scenario until he is satisfied with the results, will be just great)

e) *Updating Vensim version*

The Spanish LUCS version we use was "built" over a Vensim "Platform" for Windows 3.1 which was certainly used by many project developers in developing countries before 1997. Now it is hard to find a windows 3.1 user.

f) *Shifting Agriculture/Forest Fallow Starting calculations (initial adjustments)*

Because of necessary adjustments that LUCS has to do every 0.25 years to "build" a "balanced Shifting agr./Forest fallow relation", the values of these variables may be completely "crazy" in the first years. It would be useful to estimate an average for this period.

g) *Agriculture Land Required per Person*

In many regions the fraction of peasant's income from agriculture is quiet low (compared with other sources such as logging or cattle). In these cases, less than 0.1 ha/person could be enough for the whole population. However, the minimum value LUCS calculates for this variable seems to be 0.1 thus overestimating the actual agriculture land demand. We suggest to set the minimum value at 0.001

h) *Persons Supplied Per Ha of Managed/Unmanaged Forest Offtake*

Some forestry projects have been developed to gradually employ (or cut) people in forest activities. However—and in contrast with other parameters (like agr. productivity or population increase rates)—LUCS accepts just a constant value for this parameter, in a way that makes impossible for a project to gradually increase or decrease harvest supply during its life period. I will say also that I've used this parameter to simulate other sources of income (or employment) to reduce agriculture land demand, but never been able to do this gradually. An increase/decrease rate for this parameter would be useful.

i) *Initial Rate of Population Change/Year Population will stabilize*

In some cases annual growth rate of population may increase within the project's life time. That is, it may start at 0.04 (4%) for year one and end at 0.05 (5%) for year 30. I know this is unusual, but it seems to happen in regions that attract people for some reason (such as infrastructure development). However, LUCS does not allow this growth rate to increase, as its changing value must approach 0.

j) *Fuelwood from Tree Plantations (Cats 1, 2 & 3) and from Agroforestry but NOT from Forest Fallow*

It is not clear how LUCS defines and estimates sources and amounts of fuelwood but it does not seem to consider Forest fallow as a source, even though in tropical areas it may be the most important one.

k) *Fraction of Closed Forest Cut for Permanent Uses/ Wood Products Lifetime*

In the same way LUCS calculates carbon in wood products, it would be useful to add one more parameter for dead wood as it behaves in a very similar way. That is: there's a fraction of Closed Forest that remains as deadwood ("dead biomass") when logging and decomposes at a given rate.

l) *Managed Selective Cutting of Closed Forest*

Some forestry techniques indicate that thinning is a good practice for young (aging categories 1 & 2) or growing forests (it may improve the growing rate as well as the quality of wood). Related to these thinning practices, LUCS accepts inputs only for plantations but not for Natural (Closed) Forest where this may also be implemented.

Unfortunately, due to other WRI priorities and lack of a timing agreement, changes recommended and model updating may not be made on time for phase 3 of the present project. Instead, LUCS can be run on its present version, simulating the whole region at a project level. If needed, parts of the region which differ too much from the rest, will be run separately. This way, diversity may be included.

3.2 Data needs and sources of such data for LUCS for both sites

Identification of basic data required to run LUCS scenarios are listed in the following tables (more detailed description are given in Annex I).

Population	
Number of inhabitants in project's area	
Initial rate of population change (% year)	
Year population will stabilize	
Family size (persons)	

Land Use and Biomass	Area (Ha)	Biomass (Ton)
Total area within the project boundaries		
How many hectares in the project area and average biomass for each of the following land use categories:		
Closed forest (aging cat's 1-3)		
Opened woodland		
Agroforestry		
Permanent agriculture		
Shifting agriculture		
Degraded or grazed land		
Forest fallow land (aging cat's 1-3)		
Restored forest (aging cat's 1-3)		
Tree plantations (aging cat's 1-3)		

Wood Products and Fuelwood Use Parameters	
Fuel wood requirement (metric tons/person/year)	
Fraction of wood available for fuel wood (from tree plantations, agroforestry, closed forest, open woodland, tree plantations; in percent)	
Fraction of wood for permanent uses (from: tree plantations, closed forest)	
Predominant use of wood products	
Useful life of wood products	

Maturation Time	
Years required for forest fallow to revert to open woodland biomass if left alone	
Years required for degraded land to revert to Open Woodland biomass if left alone	
Years required for open woodland to revert to Closed Forest biomass if left alone	
Maturation time for forest plantations	

Forestry System	
Amount of Wood that can be extracted from agro forestry land for fuel wood or other purposes (Tons/ha/year)	
Number of hectares of closed forest harvested in a yearly basis (ha/year)	
Fraction of Closed forest biomass extracted or damaged during harvest (%)	
Amount of wood available for fuel wood from shifting agriculture (Tons/ha/year)	
Description of forest growing (aging categories, biomass)	
Description of plantations growing (aging categories, biomass)	
Number of hectares of closed forest effectively protected (Ha)	

Agriculture System	
Number of persons sustained by one hectare of:	
Permanent agriculture (persons/ha)	
Shifting agriculture (persons/ha)	
Agro forestry (persons/ha)	
Change in Rate of Ag Production (percentage/year)	
Initial agriculture land for export production (Hectares)	
Growth rate of Agr. land for export production (percentage/year)	
Fraction of food imported (%)	
When forest is converted, what fraction is brought to:	
Agro forestry (%)	
Permanent Agriculture (%)	
Shifting agriculture (%)	
Number of hectares suitable for permanent agriculture (ha)	
Years required for fallow to return to cultivation	
Cultivation period of shifting agr. (before fallow) (years)	

Table 1 shows data items needed and sources identified.

Table 1. Data needs, sources and strategy for obtaining

Data Type	Sources	
	Calakmul	**Meseta Purépecha**
Land Use/Land Cover	Inventario Forestal Report	Inventario Forestal Report
	Conservation International, Colegio de la Frontera Sur	GIRA, UNAM Instituto de Ecología
	INEGI	INEGI
Population/Census Data	INEGI 2000 census in CD	INEGI 2000 census in CD
	CONAPO Web site for 1995-2020 projections	CONAPO Web site trends from 1995 to 2020
	INEGI data on 10 yearly census	INEGI data on 10 yearly census
Forest System		
Forest Degradation		GIRA, A.C.
Deforestation Rates	From GEOMOD modeling efforts	From GEOMOD modeling efforts
Forest Management System	Forest management plans	Forest management Plans
Agricultural System	INEGI web search	INEGI web search
	Personal information, PRONATURA, TNC	Avocado Associations, GIRA, UNAM, various publications
Wood Products and Fuelwood	TNC, personal information	GIRA, UNAM, various publications
Other Land Use Change Drivers—Commercial Agriculture, Water Availability	PRONATURA, TNC	GIRA, A.C., UNAM Instituto de Ecología
	Web search	GIRA, UNAM
Land Tenure	From GEOMOD work	From GEOMOD work
Boundary of Project Area	GEOMOD work	GEOMOD work
Biomass	Peten maps, Inv. Forestal, Ecosur work, various publications, TNC, personal information	Inventario Forestal Project team/GIRA (various publications)

By means of web searching, contacting key people at both regions, visiting them, purchasing tabular and spatial information and maps and using personal information available, the documents listed in Table 1 above were acquired. Specific documents containing data acquired, including examples, for Calakmul and Meseta Purépecha to develop baselines using LUCS are listed below (these data are also useful for the other two models):

Meseta Purépecha (Michoacán)

A) Population (excel tables and 1 cd-rom):

- <u>Pob. Michoacán 1950-2000</u>: Increase rate data in a 10 year basis at State level (Table 2).

- <u>Michoacan</u>: CONAPO Pop. Projection 1995-2020 State level; 1995-2010 Municipal level (all the Michoacán municipios).

- <u>Meseta Purépecha Pob. 1995-2010</u>: CONAPO Pop. projection for the Meseta Purépecha at municipal level (Fig. 1).

- <u>Mich. Crec. Demografico INEGI</u>: 1895-2000 Pop. projection in a 10 year basis at state level.

- <u>Mich. (municip) 1990-2000 INEGI</u>: 1990-2000 increase rate at municipal level for all the municipios in the state of Michoacán.

- <u>2000 Population Census CD-ROM (INEGI)</u>

Table 2. Tasas de Crecimiento Promedio Anual de la Población, 1950-2000, for Michoacan (from INEGI)

Período	Nacional	Entidad
1950–60	3.1	2.7
1960–70	3.4	2.4
1970–80	3.2	2.1
1980–90	2	2.2
1990–2000	1.9	1.2

Nota: Las tasas pueden diferir de las derivadas de otros cálculos y ajustes especiales en los datos, en particular las que involucran cifras de 1980, debido a los problemas de subcobertura que afectaron al Censo de ese año en la entidad.
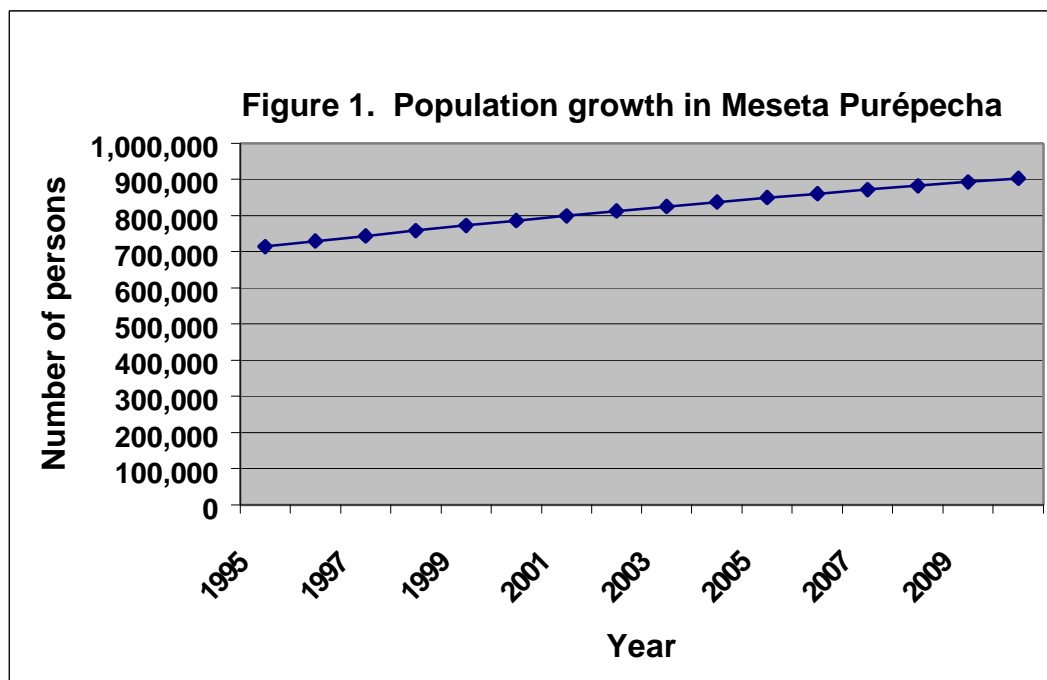
B) Fuelwood

- Fuelwood: 2 tables with fuelwood consumption (industrial and domestic) for the Meseta Purépecha (Table 3).

Table 3. Proportion of Population in Meseta Purepecha Using Fuelwood (Fuentes tabla anterior: Adaptado de INEGI (2001) y Díaz (2000). Díaz R. 2002. Correspondencia personal; Incluye urbano y rural)

Municipio	Poblacion Total	Poblacion Total Usa leña	% de POBTOT
Charapan	10898	8,746	80%
Cheran	2979	2,652	89%
Chilchota	30711	21,196	69%
Erongaricuaro	13161	8,655	66%
Nahuatzen	7954	5,435	68%
Nuevo Parangaricutiro	15280	6,810	45%
Paracho	31096	18,273	59%
Patzcuaro	77872	28,219	36%
Periban	20256	6,678	33%
Quiroga	23893	10,490	44%
Reyes, Los	57006	20,049	35%

Municipio	Poblacion Total	Poblacion Total Usa leña	% de POBTOT
Salvador Escalante	38331	27,001	70%
Tancitaro	25670	19,080	74%
Tangancicuaro	32821	11,322	34%
Taretan	13287	6,756	51%
Tingambato	11742	7,969	68%
Tzintzuntzan	12414	7,423	60%
Uruapan	265699	41,342	16%
Ziracuaretiro	12879	7,083	55%

C) Land Tenure

- tbe_mich: PDF file, very comprehensive document with information at municipal level, containing number and type of communities (ejidos, comunidades), area, land tenure for each community.

- Ejidos y Comunidades 1991: Excel file with information at municipal level about land tenure, area, land use.

D) Forest:

- Existencias forestales: Excel table with data about forest cover, wood stocks, forest classes, volumes, growth rate & erosion for the Meseta Purépecha at municipal level (Table 4).

Table 4. Area (ha) of forest by cover/volume class

Superficie con cubierta forestal por clase de bosque (Ha)						
Municipio	**clase1 (<=50m3/ha)**	**clase 2 (50-100 m3/ha)**	**clase 3 (100-200 m3/ha)**	**clase 4 (200-300 m3/ha)**	**clase 5 (>300 m3/ha)**	**Total**
Charapan	1,308	1,428	4,227	1,390	234	8,587
Cheran	0	1,551	8,174	3,601	630	13,956
Chilchota	3,155	7,333	3,137	0	0	13,625
Erongaricuaro	1,466	274	4,041	329		6,110
Nahuatzen	1,556	1,455	8,510	1,348	570	13,439
Nuevo Parangaricutiro	186	236	4,718	8,065	237	13,442
Paracho	1,837	3,226	3,796	2,232	0	11,091
Patzcuaro	547	3,829	6,455	2,963	428	14,222
Periban	849	2,049	2,103	2,750	1,343	9,094
Quiroga	1,321	2,047	2,439	52	134	5,993
Reyes, Los	884	1,374	10,612	2,368	4,552	19,790
Salvador Escalante	1,014	1,680	11,141	2,843	2,775	19,453
Tancitaro	2,225	4,524	8,294	5,046	2,291	22,380
Tangancicuaro	2,488	1,413	4,320	937	27	9,185
Taretan	1,769	2,824	2,457	0	0	7,050
Tingambato	90	295	5,351	1,123	179	7,038
Tzintzuntzan	382	982				1,364
Uruapan	9,069	15,890	12,730	1,737	424	39,850
Ziracuaretiro	281	2,774	9,326	663	0	13,044

- inv_for_mich 2: Word file in spanish, extracted from 1995 Michoacán forest inventory. Contains information about historical data and environmental issues at state & physiographic regions levels.

- mich 3: Word file in spanish, extracted from 1995 Michoacán forest inventory. Vegetation types, forest area, wood stocks at state level.

E) Land Use Change drivers:

- avocado: Word document in spanish with historical data of area. Various sources.

- agr. Mich. INEGI 2000: Excel file with information about agricultural production at state level. Main crops.

- <u>Unid. Prod. Rural 1991 INEGI</u>: Excel file. Data at state level for number and types of rural production units and land tenure.

- <u>1st Avocado Congress; Uruapan, Michoacán; 15-20 Oct. 2001</u>. contains information about avocado environmental requirements in Michoacán.

- <u>Forest resources dynamics in the Purépecha Region; GIRA (Omar Masera); 1988</u>

Calakmul

A) Population (excel tables and 1 CD-ROM)

- <u>Pob. </u>Campeche 1950-2000 INEGI: Increase rate data in a 10-year basis at State level.

- <u>Pob. Campeche (proy 1995-2010)</u>: CONAPO Pop. Projection 1995-2020 State level; 1995-2010 Municipal level (all the municipios of Campeche, Fig. 2)

Figure 2. Population projections in Calakmul study area
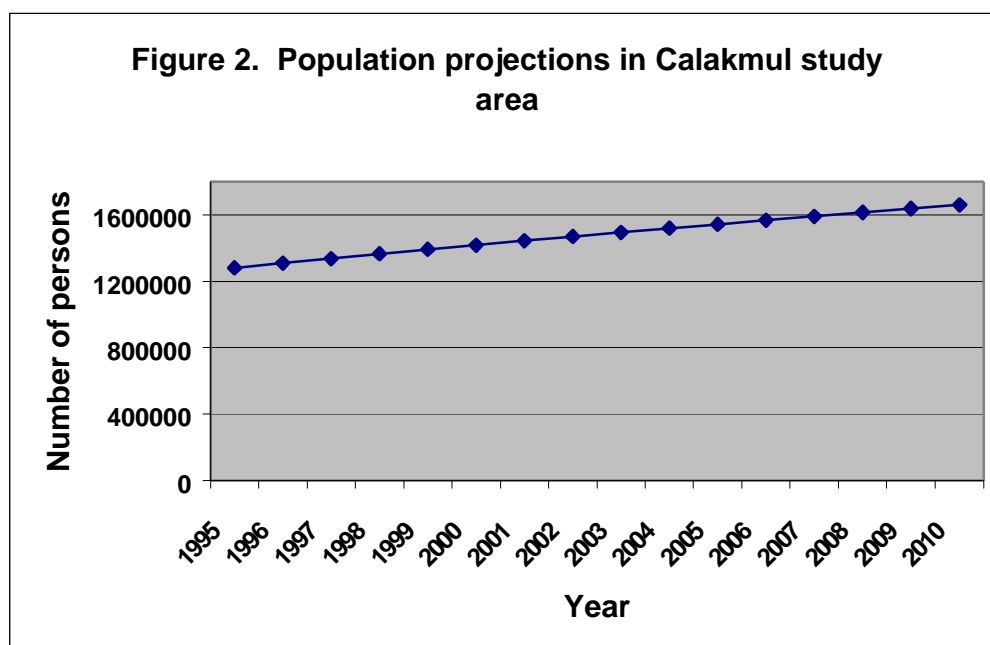
- <u>Camp. Sociodemograf INEGI</u>: 1990-2000 increase rate at municipal level for all the municipios in the state of Campeche.

- <u>2000 Population Census CD-ROM (INEGI)</u>

B) Land Tenure

- <u>tbe_cam</u>: PDF file, very comprehensive document with information at municipal level, containing number and type of communities (ejidos, comunidades), area, and land tenure for each community.

C) Land Use Change drivers

- <u>agr. Campeche</u>: Excel file with information about agricultural production at state level, including main crops.

D) Calakmul Reserve Management Plan (2 files)

E) Geohydrological map (INEGI)

F) TNC: Calakmul Climate Change Mitigation Project

3.3   The GEOMOD2 Model

The second model that will be used is GEOMOD 2, a spatially geo-referenced model, that combines "layers" of critical data including socioeconomic, demographic, and biophysical drivers of land-use change, overlain according to the model's rules in a geographic information system (GIS) platform. Details of the data needs and basic structure of the model are given in Annex 3. We first report on specific data needs and acquisition for the Calakmul region and then for the Meseta Purepecha region. All data acquired are in a format that can be manipulated by the model—some data were acquired already in digital format and others we have digitized as part of this work.

Calakmul Region

To model the 'business as usual' carbon baseline for the Mexican State of Campeche portion of the Calakmul Biosphere Reserve and its surrounds we identified the data needs listed in Table 1. We present a summary of our data collection efforts, the boundary of the proposed region to be modeled and images to illustrate each. Table 5 lists the attribute information, the source, the date of information, the original projection, and indication of whether the data covers the defined study area. Where data are not indicated as complete we are awaiting delivery of full coverage of the missing regions from INEGI (ordered but waiting for delivery). The data to fill in these holes are referenced in the data table by map sheet (*hoja*). All data sets are being converted to UTM-16n projection, NAD27 Datum, Clarke 1866 Reference Elipsoid.

Table 5. Data needs and acquisition success for the Calakmul Project.

Data Type	Source	Date	Original Proj.	Complete Cov.	Figure #
Vegetation 1970s	INEGI (Ecosur)	1970s	UTM-15n		*
Vegetation 1990s	Conservation International	1995/6	Transverse Mercator	X	3
Reserve Outline	Conabio(Ecosur)	—	UTM-16n	X	3
Study Area	Based on deforestation pattern evident in region to west	—	UTM-16n	X	3
Ejidos	Clark University	1990s	Lat/Lon	X	4
Hydrology	Conabio(Ecosur)	—	UTM-16n		5
Surface Water Inunda Bajos/Aguadas	Conabio (Ecosur)	—	UTM-16n		6
Roads	Conabio(Ecosur)	—	UTM-16n		7
DEM (digital elevation model)	INEGI (NALC project… USGS)	—	UTM-16n		8
Elevation Contours	Conabio (Ecosur)	na	UTM-16n, tabular		9
Census 2K	INEGI—see above under the LUCS model	2000	UTM-13		
Pueblos	Conabio (Ecosur)	?	UTM-16n		10
Vegetation 2000 Landsat ETM Image, Path 20, Row 47, unclassified	B. Turner, Clark University	2000	?	Need Path 20, Row 48 to cover study area	11
1:50,000 scale data for areas not covered by Ecosur data set. These include: Constitucion (E15B69) X_Bonil (E15B59), and Yohaltun (E15b49).	INEGI				*
1:250,000 vectorial data sets & toponimic for Ciudad de Carmen E1506) and Chetumal (E1604)	INEGI			X	*
Vegetation in the Calakmul Biosphere Reserve	Ecosur	1995-6	UTM-16n		12
Communication Infrastructure	Conabio (Ecosur)		UTM-16n		*

(* awaiting delivery)

Figure 3. 1995-6 Vegetation Map from the Conservation International Mosaic (contact Daniel Juhn) windowed to Project Study Area (coordinates = xmin 128632.79, xmax 275175.74, ymin 1970596.25, ymax 2131978.99). Calakmul Reserve Boundary visible.
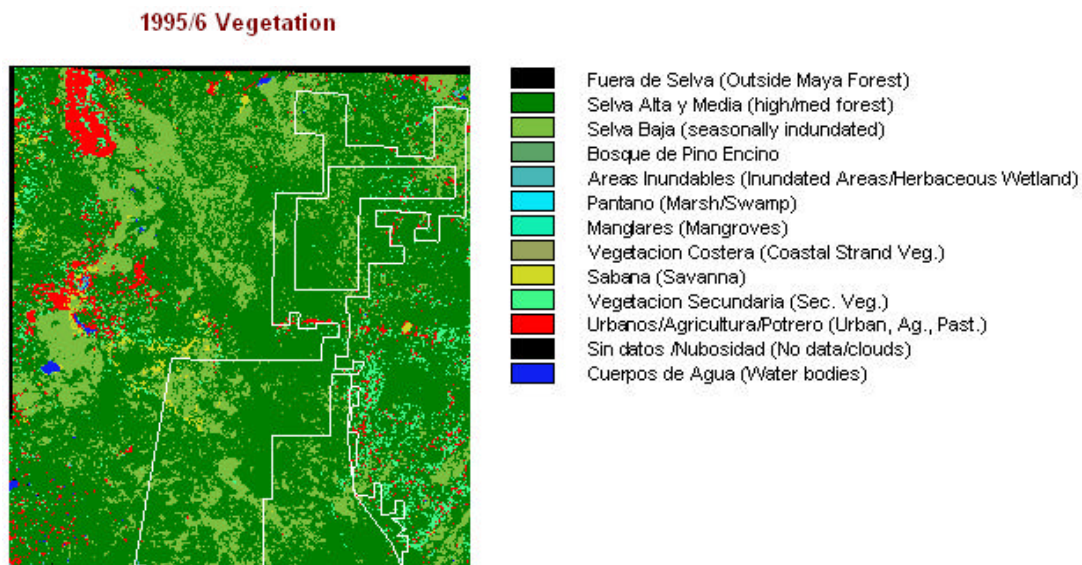

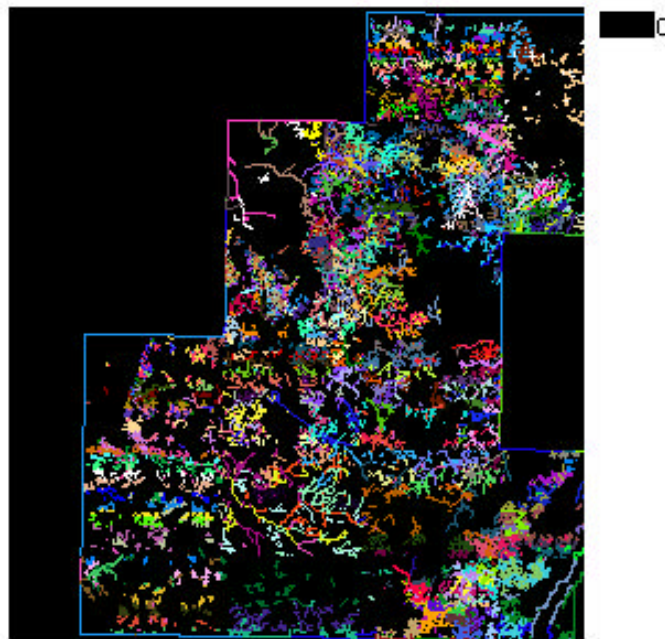**Figure 4. Ejidos map (from B. Turner, Clark University)**

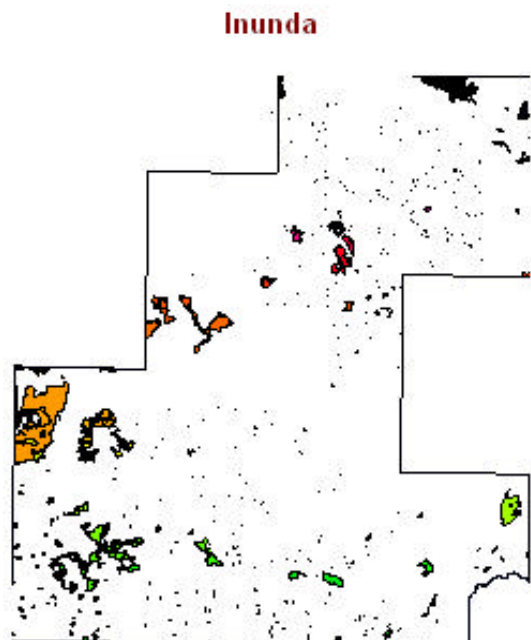**Figure 5. Hydrology**

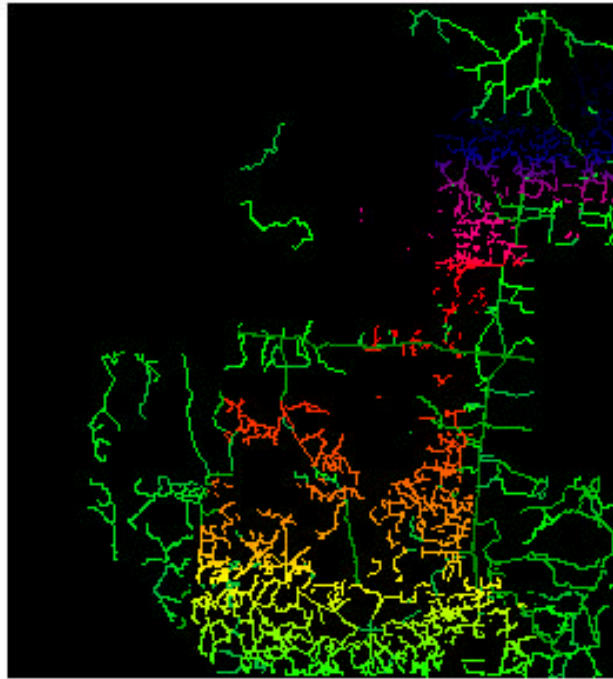**Figure 6. Surface Water—lakes, bajos, aguadas**

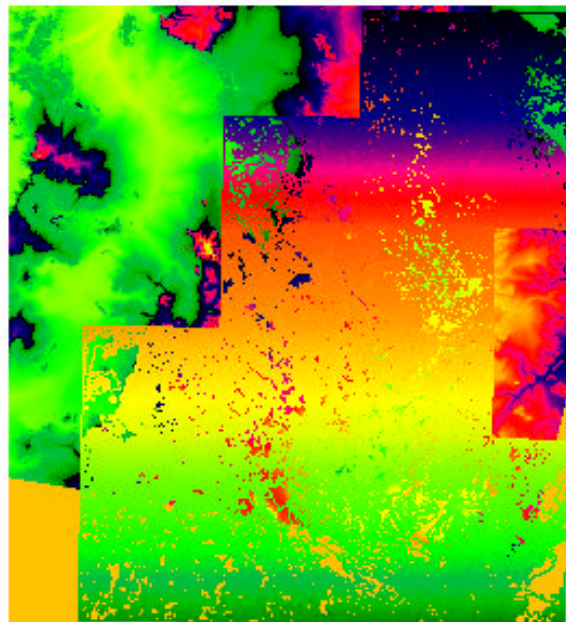**Figure 7. Roads**

Figure 8. Elevation Data
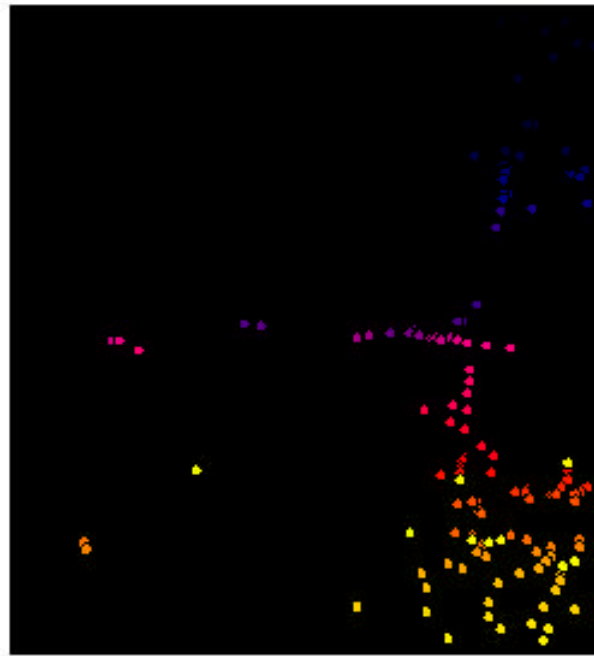
Figure 9. Pueblos

Figure 10. Landsat-ETM Imagery, Year 2000, Path 20, Row 47 (source B. Turner, Clark University)
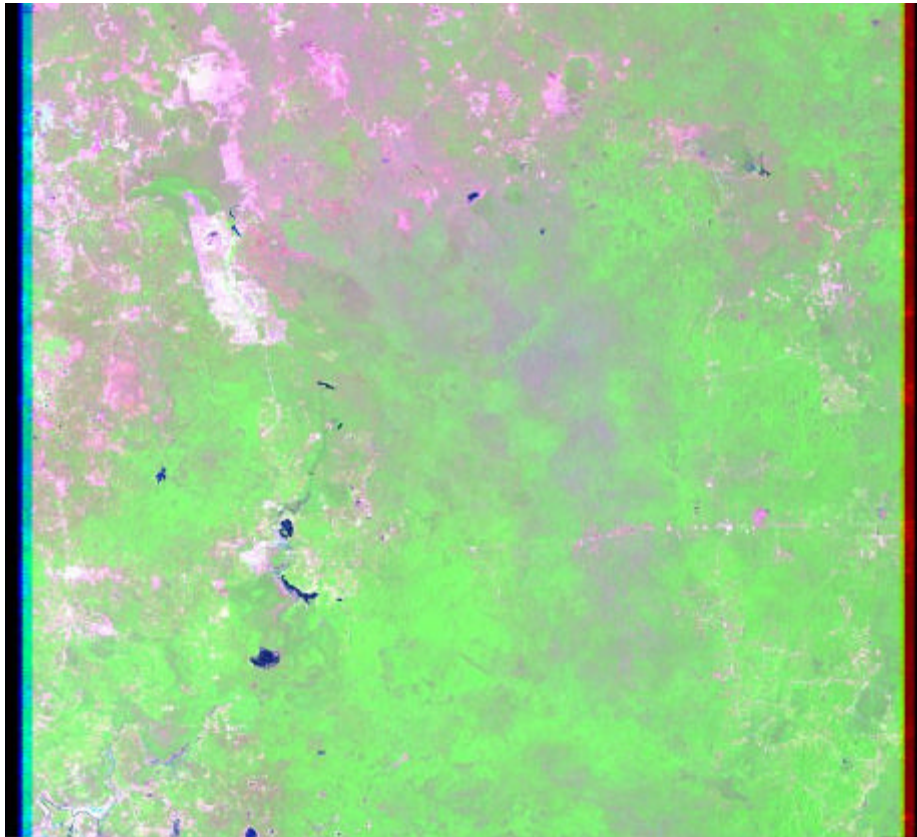
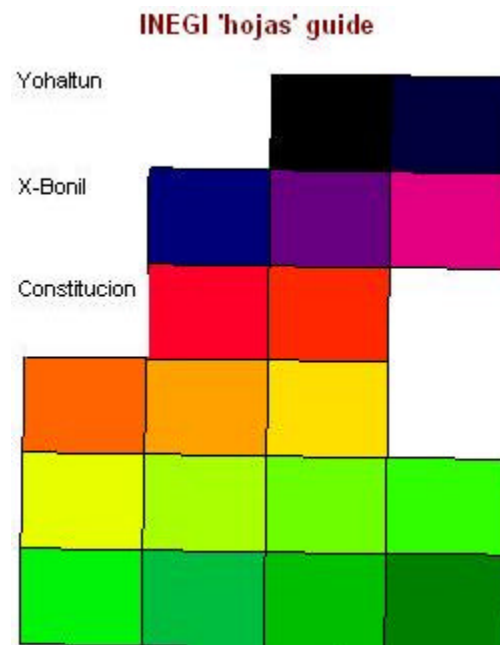**Figure 11. 1:50,000 scale data purchased from INEGI**

Figure 12. Vegetation in the Calakmul Biosphere Reserve

Meseta Purepecha

Meseta Purepecha region in Michoacan is comprised of 19 municipios (Fig. 13).

Figure 13. Map of study region Meseta Purepecha

Meseta P'urepecha's Municipality
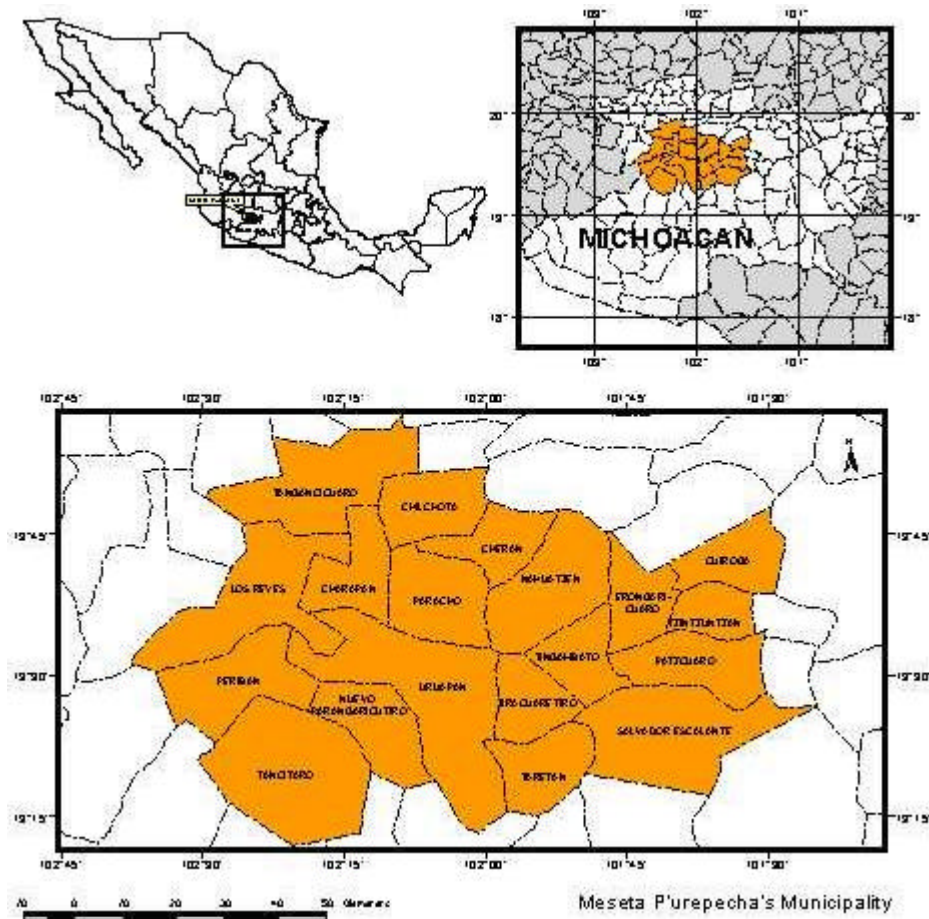
The following data have been obtained for this region:

1. Topography (altitude, slope, roads, hydrology, towns, etc.) The data are the topography vector data set, scale 1:50,000, produced by Instituto Nacional de Estadística, Geografía e Informática (INEGI) have been obtained.

2. Land cover and land use data. These have been purchased and represent the land use and vegetation vector data sets for the 1970s (Fig. 14) and 1990s (Fig. 15) produced by INEGI.

Figure 14. Map of land use encompassing the Meseta Purepecha region for the 1970s

Carta Uso de suelo y vegetación Serie I
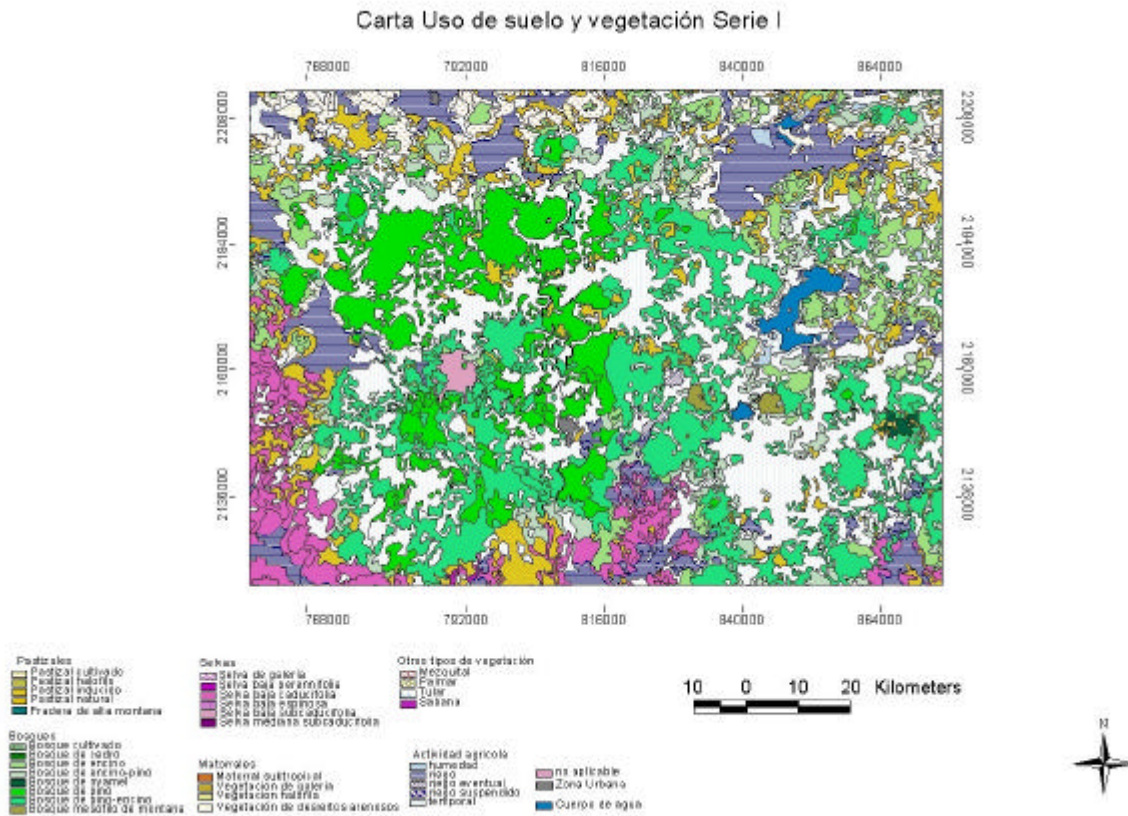
Figure 15. Map of land use encompassing the Meseta Purepecha region for the 1990s
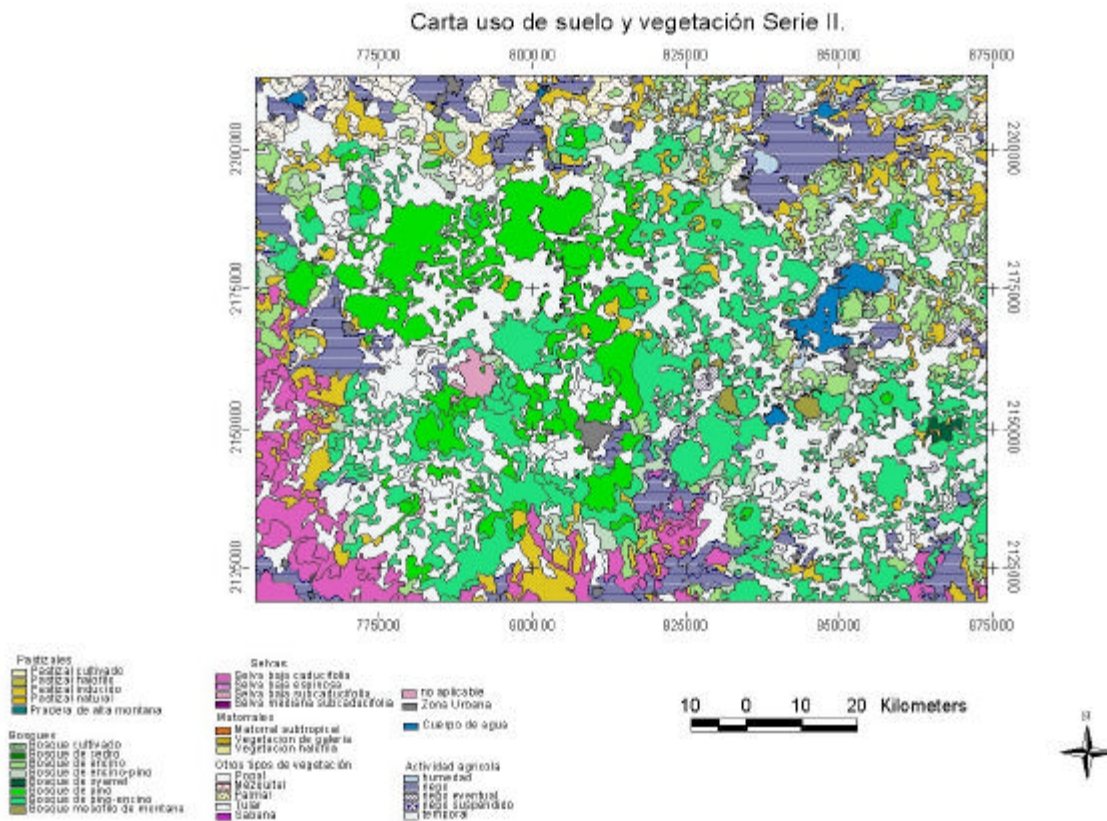
3. Instituto de Geografía provided us with a preliminary version of the National Forest Inventory map for 2000 year (Fig. 16).

4. Population data—described above under the LUCS model (e.g. see Fig. 1 for projected population growth).

5. Protected areas. Laboratorio de Geoecología provided us with the map for the one protected area in the region The Tancítaro Mountain (Fig. 17).

6. Climatic effects. We subcontracted with a group to digitize the main climatic effects for the region (min. and max. temperature and total rainfall amount) for the rain season (May to October) and the dry season (April to November).

Figure 16. Preliminary version of the National Forest Inventory map for 2000

Land cover for the Meseta area.
Source: National Forest Inventory 2000. Instituto de Geografía-Semarnap.
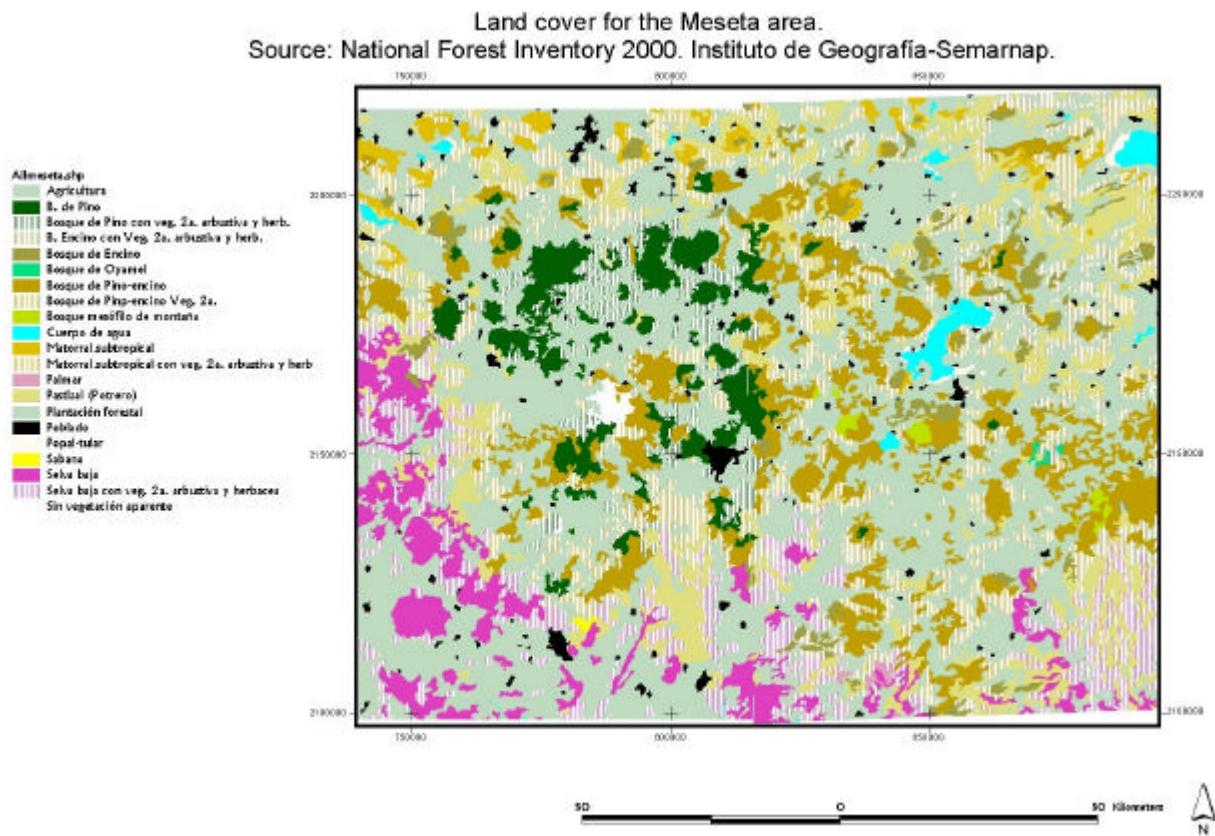
Figure 17. Map of a key protected area in the Meseta Purepecha—the Tancítaro Mountain
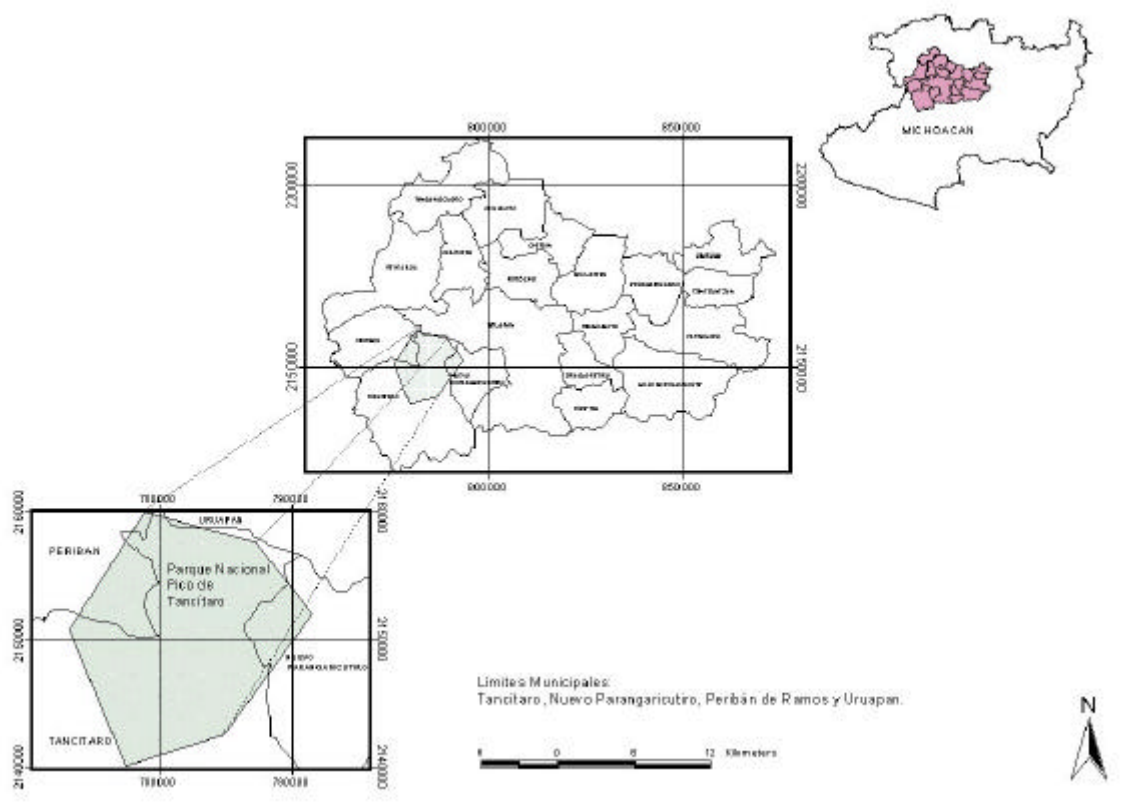
Avocado is an important crop in this region and forests are being converted to this practice—the increase in area of avocado (Tables 6-7) generally comes at the loss of native forest cover.

Table 6: Superficie de aguacate en todo el Estado de Michoacán (Mendoza Arroyo, 1995)

Year	Area (ha)
1970	3 708
1975	10 186
1980	21 241
1985	44 138
1988	59 536

Table 7. Superficie de aguacate (in ha) al nivel de municipio aporta datos de 1987 y 1989m et incluye "superficie en desarrollo" y "superficie en producción

Municipio	1987	1989
Uruapan	16842	25000
Tancítaro	14845	18000
Peribán	12048	11000
Tacámbaro	8015	9360
San Juan Nuevo	2513	8500
Los Reyes	958	6400
Otros	23959	13827
Total	*79180*	*92087*

3.4   Model of Forest Cover and Human Demographics

The third approach will extrapolate historical tabular data on changes in land use using a model based on forest cover and population. This model was developed by staff of the FAO for the Forest Resources Assessment Project and was based on an extensive data base for developing relationships between past trends in land use change and population (Annex 4 for details of the model). We will use this model, which can be made regionally specific, to project forward land use change based on projections of population growth. Projections of population growth over the proposed project duration have been obtained already from INEGI (see above under the LUCS model section) and will be used for this effort too.

Data on deforestation for this model overlaps with those for the other models and as those data are analyzed they will be incorporated into the deforestation model.

Carbon Content of Forests

Carbon contents of the various forest classes will be obtained from existing data and methods. Methods for converting forest inventory are well established (e.g. Brown 1997) and will or have already been applied to existing forest inventory data. Other data available are those collected by the UNAM team for the Meseta Purepecha region. Data for the Calakmul region will come from various sources including the national forest inventory and other ecological studies done by Ecosur team and B. Turner's group. For example, data for secondary forests in the Calakmul region are in the process of being obtained from work in press by colleagues of B. Turner at Clark University (Read et al., in review).

Data in Table 8 represent conversion of forest inventory data to carbon estimates and will be used where appropriate in this study. Several of the forest types are common to Campeche and several identified in italics could be appropriate for the Meseta Purepecha region. In addition we have on hand forest inventory data for the Meseta region as described above under the LUCS model (e.g., Table 4).

Table 8. Mean total biomass densities (TBD) of hybrid land use/land cover classes, numbers of plots used, confidence intervals (CI) and states where the densities were applied

No.	Class	TBD (Mg/ha)	n	90% CI	State
1	Cultivated Land	12.0	249	0.83	Yu, Ch, Oa, Ve
1	*Cultivated Land*	*17.9*	*160*	*1.68*	*QR, Ca, Ta, Gu*
2	Pasture/grasslands/savanna	21.8	219	0.80	QR, Yu, Ch, Ca, Oa
2	*Pasture/grasslands/savanna*	*28.1*	*247*	*1.62*	*Ve, Ta, Gu*
3	Closed fir forest	209.3	4	142.73	All
4	Open fir forest	53.3	5	32.92	All
5	Closed cloud forest	149.8	36	29.29	All
6b	Open cloud forest	40.2	62	2.11	All
7	*Closed oak forest*	*69.4*	*96*	*15.15*	*Ch, Gu*
7	Closed oak forest	104.2	49	20.17	Oa, Ve, Ta
8b	Open oak forest	40.2	546	2.11	All
9	Closed pine forest	179.6	49	27.74	All
10c	*Open pine forest*	*92.8*	*421*	*12.94*	*Gu*
11	*Closed pine/oak forest*	*171.8*	*110*	*16.64*	*Oa, Ve, Gu*
12c	*Open pine/oak forest*	*92.8*	*421*	*4.95*	*Gu*
13	Closed other conifer forest	155.7	5	89.56	All
14	Open other conifer forest	39.8	4	13.76	All
15b	Fragmented forests and selvas	40.2	225	2.11	All
16	*Tall/medium selva*	*41.1*	*55*	*5.96*	*Gu*
16	Tall/medium selva	133.1	831	6.30	QR, Yu, Ch, Ca, Oa,Ta
17	*Short selva*	*31.6*	*204*	*4.45*	*Ch, Oa, Ve, Ta, Gu*
17	Short selva	85.2	388	6.38	Qr, Yu, Ca
18	Perturbed areas	18.7	41	2.90	QR, Ch, Ca, Oa, Ta
18	*Perturbed areas*	*28.2*	*127*	*2.78*	*Yu, Ve, Gu*
19	Agricultural plantations	36.3	122	4.36	All
20	Forest plantations	108.2	7	44.07	All
21	Chaparral	12.3	81	0.82	QR, Ch, Ca, Oa, Ve
21	*Chaparral*	*23.8*	*20*	*3.58*	*Yu, Gu*
22	Xerophytic matorral	14.2	8	6.91	All
23	Other	0.0	205	N/A	All

a. Yu=Yucatan, Ch=Chiapas, Oa=Oaxaca, Ve=Veracruz, QR=Quintana Roo, Ca=Campeche, Ta=Tabasco, Gu=Guerrero.

b. Class TBD means not statistically different, thus were combined for computing statistics.

c. Class TBD means not statistically different, thus were combined for computing statistics.

d. Red: few samples; Blue: comparable classes; Italics: may be applicable to Michoacán.

We have also identified biomass regression equations that will be useful for converting any forest inventory data of tree diameter/height to biomass carbon (from Ayala-Lopez 1998)—these are (Table 9, where TB is total aboveground biomass in kg dry weight, D [dbh] in cm, H [height] in meters):

Table 9. Regression equations for oak and pine species of Mexico for estimating biomass of forests

Equations	Dbh-limits	N	R^2	R^2-corr
Oak (5 species)				
$TB = 1.91 * D^{1.782}$	5 -109	50	.926	.853
$TB = 0.283 (D^2.H)^{0.807}$	5 -109	50	.954	.908
$TB = 56.335 + 0.773 * D^2$	5 -109	50	.843	.84
$TB = 287.758 + .026 * D^2 H$	5 -109	50	.891	.889
Pine (6 species)				
$TB = 0.084 * D^{2.475}$	10-115	80	.972	.936
$TB = 0.058 * (D^2 H)^{0.919}$	10-115	80	.97	.932
$TB = -399.073 + .737 * D^2$	10-115	80	.921	.92
$TB = 157.341 + .021 * D^2 H$	10-115	80	.928	.927

Similar equations are in Brown and Schroeder (1999) and Schroeder et al. (1997) for temperate hardwood and softwood species.

3.5   Summary

Here we have presented the three models and identified and acquired (still waiting for delivery of some items) a rich data set needed to simulate them and develop the baselines. The spatial and socio-economic data base is the most complete and will be available for simulating scenarios of land-use change. The carbon density data of land-use/land-cover classes are less complete, particularly of some converted land uses (such as avocado plantations); however the vast experience by the team in measuring carbon in the landscape and the available methods does provide us with the tools necessary to accomplish this task of estimating carbon densities.

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Schroeder, P., S. Brown, J. Mo, R. Birdsey, and C. Cieszewski. 1997. "Biomass Estimation for Temperate Broadleaf Forests of the US Using Inventory Data." *Forest Science* 43: 424–34.

Annex 1. Data Required To Run LUCS

1. Land Use Categories

a) Area

Permanent Agriculture = The number of hectares of agricultural land in continuous cultivation. (Hectares)

Agroforestry Land = Land use system in which woody perennials are used on the same land as agricultural crops or livestock. (Hectares)

Shifting Agriculture = The number of hectares of shifting agricultural land that lies within the project area. It is defined as a farming system in which land is periodically cleared, farmed, and then returned to fallow. It is also referred to as slash-and-burn or swidden agriculture. (Hectares)

Forest Fallow = Like Closed Forest and Restored Forest, Forest Fallow is divided into three aging categories which approximate the tree growth curve.

- *Forest Fallow Cat 1* = The total number of Forest Fallow Aging Category 1. Aging Category 1 represents the first growth. (Hectares)

- *Forest Fallow Cat 2* = The total number of hectares of Forest Fallow Aging Category 2. Aging Category 2 represents the secondary growth. (Hectares)

- *Forest Fallow Cat 3* = The total number of hectares of Forest Fallow Aging Category 3. Aging Category 3 represents the mature closed forest, before forest fallow can be returned to agricultural production, or matures into open woodland or closed forest. (Hectares)

Often data concerning the number of hectares in forest fallow are difficult to obtain. If data are nonexistent, the model can calculate the area based on the following formula: Initial ff1=Shifting Ag Land*((Maturation Time of Forest Fallow, Rotation Length of Shifting Ag Land)/3)*(1-Degradation of Shifting Ag).

Open Woodland = How many hectares of open woodland lies within the project region? Open woodland is forest in which the tree canopy layer is discontinuous but covers at least 10 fraction of the area. (Hectares)

Total Closed Forest = Closed forest is a forest in which the tree crowns approach general contact with one another. Initial Closed Forest is the TOTAL amount of closed forest in the project region, including aging categories 1,2, and 3. (Hectares)

- *Closed Forest Cat 1* = Each forest system's (tree plantations, closed forest, restored forest) growth pattern is represented by three aging categories. The third category represents the mature forest, the first category is the minimum biomass while still maintaining a closed canopy and aging category 2 is the average of the first and third categories. This aging chain

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approximates a typical S-shaped forest growth curve. The top of the S curve is a mature forest, then divide the curve into thirds. Determine how much of the closed forest in the project area falls into each area of the S curve. This variable represents the number of hectares which fall into the first third of the S curve at the project's beginning. (Hectares)

- *Closed Forest Cat 2* = At project start time the number of hectares of closed forest which fall into the second third of the S shaped curve, or number of hectares of closed forest which contains roughly the amount of biomass of an average of the first and third categories. (Hectares)

Tree plantations = stands of trees, or wood lots raised for the production of industrial forest products (for example, sawlogs, veneer logs, pulpwood, poles and pitprops).

- *Tree Plantations Cat 1* = Of the total land in tree plantations, how many hectares are in aging category 1? (Hectares)

- *Tree Plantations Cat 2* = Of the total land in tree plantations, how many hectares are in aging category 2? (hectares)

- *Tree Plantations Cat 3* = Of the total land in tree plantations, how many hectares are in aging category 3? (Hectares)

Restored forests = areas which were once forested but due to land conversion or degradation were reforested. Then, efforts were made to restore the area to its former state. Restored forests are not harvested. For an explanation of the aging categories, please see the explanation for Closed Forest Category 1

- *Restored Forest Cat 1* = Of the restored forest land, how many hectares are in aging category 1 or newly planted restored forest? (Hectares).

- *Restored Forest Cat 2* = Of the restored forest land, how many hectares are in aging category 2? (Hectares)

- *Restored Forest Cat 3* = Of the restored forest land, how many hectares are in aging category 3? (Hectares)

Degraded Land = Degraded land is land on which biological, chemical, and physical processes prevent natural regeneration. Since the amount of biomass on grazed and degraded land is similar, they have been put in the same category. This variable is the total hectarage of degraded land or land used for grazing. (Hectares)

b) Biomass

Biomass refers to all the living organic material in that particular land use category. The amount of biomass for each category of land use is an average of that land use type expressed in tons per hectare. Depending on your available data, this number may also include soil biomass. This number should represent the average biomass for all of the particular land type in the project area. (Tons/Hectare)

Mature Closed Forest Biomass = This number should represent the average biomass for all mature closed forest in the project area. (tons/hectare)

Ratio of Closed Forest Aging Cat 1 to Mature Forest = What is the fraction of biomass of first aging category of closed forest to mature closed forest. This variable can be used to highlight the difference between biomass removed in conventional logging versus sustainable or reduced impact logging. Under Unmanaged Logging the harvest results in Mature Closed Forest being converted to Closed forest Aging Category 1. (Fraction)

Ratio of Closed Forest Aging Cat 2 to Mature Forest Max = What is the fraction of biomass of second aging category of closed forest to mature closed forest. This variable can also be used to highlight the difference between biomass removed in conventional logging versus sustainable or reduced impact logging. Under Managed Logging the harvest results in Mature Closed Forest being converted to Closed forest Aging Category 2, while under Unmanaged Logging Mature Forest is converted to Aging Category 1. (Fraction).

2. Population

Initial Population = The population of the region or project area at the beginning of the project. (Persons)

Family Size = Estimate the average family size in your project area. (Persons)

Initial Rate of Population Change = The rate of population increase or decrease. (Fraction/year)

Year population will stabilize = Year population is expected to stabilize, when population growth is approximately zero. (Year).

3. Fuelwood Use:

Fuelwood Requirement per Person = Tons of fuelwood that each person uses per year. (Tons/person/year)

Fuelwood from Tree Plantations Cat 1 = Harvest from tree plantations can be both destructive and non-destructive. As tree plantations mature, they need periodic thinning to produce optimal growth to produce optimal growth. The model assumes that no wood from Aging Category 1 can be used for permanent uses. (tons/hectares/year)

Fuelwood from Tree Plantations Cat 2 = Estimate the tons of fuelwood (this will frequently be expressed as a fraction) per hectare per year of fuelwood available from Aging Category 2. (Tons/hectares/year)

Fuelwood from Tree Plantations Cat 3 = Estimate the tons of fuelwood (this will frequently be expressed as a fraction) per hectare per year of fuelwood available from Aging Category 3. (Tons/hectares/year)

Fuelwood from Agroforestry Land = How many tons of wood per year can be taken off of agroforestry land for fuelwood? (Tons/hectare/year)

Fraction of Wood from Closed Forest Conversion Available for Fuelwood = When closed forest is converted to any other land use, what fraction of the biomass is available for fuelwood. (Fraction)

Fraction of Wood from Open Woodland Conversion Available for Fuelwood = When open woodland is converted to any other land use, what fraction of the wood is available for fuelwood. (Fraction).

Additional Stoves = What, if any, is the number of additional fuel efficient stoves the project would provide per year until the Project End Time. The stoves may be solar or fuelwood, among others. (Stoves/year)

Fraction of Fuelwood Savings =The reduction in fuelwood use due to the fuelwood-reducing stoves provided by the project. (Fraction/year)

4. Natural Recovering

Recovery Time for Degraded Land to Open Woodland = If left alone, how long will it take for degraded land to recover to open woodland. In some projects, degraded land may never recover without intervention. For example, soil degradation due to acid rain meant recovery may never occur in Krkonose Park in the Czech Republic, so a Recovery Time of 200 years was used. (Years)

Time Required for Open Woodland to Revert to Closed Forest = How many years are required for open woodland to revert to closed forest if left alone? (Years).

Time for Fallow to Return to Cultivation = How many years are required before fallowed land can be brought back into shifting cultivation? (Years)

Time for forest fallow to return to open woodland = How many years are required for forest fallow 3 to return to open woodland if left alone? (hectares/year)

5. Agriculture System

Initial Ag Land for Export Production = At the projects beginning, how many hectares of agricultural land is used for export production? (Hectares)

Growth Rate of Ag Land for Export = The rate of change of agricultural land used for export production. (Fraction/year)

Fraction of Food Imported = The fraction of food which is imported into the project area versus being grown locally. (Fraction)

Initial Fraction of Land Brought into Permanent Ag Production = When land is converted from forest, what fraction of hectares goes into permanent agricultural production versus shifting agricultural land and agroforestry. (Fraction)

Initial Fraction of Land Brought into Shifting Ag Production = When land is converted from forest, what fraction of hectares goes into shifting agricultural production versus permanent or agroforestry production. (Fraction)

Initial Fraction of Land Brought into Agroforestry Production = When land is converted from forest, what fraction of hectares goes into agroforestry production versus permanent or shifting agriculture. (Fraction)

Change in Fraction of Land brought into Permanent Ag = If the project changes the amount of land, by how much does the fraction of land converted to agroforestry change? This change only occurs until the Project End Time, and then reverts to the Initial Fraction Brought into Permanent Ag. (Fraction)

Change in Fraction of Land brought into Shifting Ag = If the project changes the amount of land, by how much does the fraction of land converted to agroforestry change? This change only occurs until the Project End Time, and then reverts to the Initial Fraction Brought into Shifting Ag. (Fraction)

Change in Fraction of Land Brought into Agroforestry = If the relative amount of agricultural land in agroforestry, versus permanent or shifting agriculture changes, by how much does the fraction of land converted to agroforestry change? This change only occurs until the Project End Time, and then reverts to the Initial Fraction Brought into Agroforestry. (Fraction)

Ratio of Productivity of Agroforestry to Permanent Ag = In the LUCS model, agricultural productivity is defined as the amount of land required to support one person. More productive systems require less land to support a person. The model calculates the amount of Required Ag Land by using a productivity ratio of shifting ag and agroforestry to permanent ag (which is the base so is equal to 1). For example, if Agroforestry supports half the number of people then its Ratio of Productivity is equal to .5. If it supports twice as many then its Ratio of Productivity is equal to 2. If there is not Permanent Ag, then use Shifting Ag as the base and make the Ratio of Productivity of Shifting Ag to Permanent Ag equal 1 and relate the productivity of Agroforestry to Shifting Ag. (Ratio)

Ratio of Productivity of Shifting Ag to Permanent Ag = In the LUCS model, agricultural productivity is defined as the amount of land required to support one person. More productive systems require less land to support a person. The model calculates the amount of Required Ag Land by using a productivity ratio of shifting ag and agroforestry to permanent ag (which is the base so is equal to 1). For example, if Shifting Agriculture supports half the number of people then its Ratio of Productivity is equal to .5. If it supports twice as many then its Ratio of Productivity is equal to 2. If there is not Permanent Ag, then use Shifting Ag as the base and make the Ratio of Productivity of Shifting Ag to Permanent Ag equal 1. (Ratio)

Maximum Permanent Ag Land = The number of hectares in the project area that are suitable for continuous cultivation. It is not necessary that the hectares currently be in continuous cultivation; but the land must be capable of supporting permanent agriculture. LUCS will not allow anymore land to be used as Permanent Ag Land than this Maximum amount. For example, if you input

1000 hectares, there will be no more than 1000 hectares in Permanent Ag Land, this variable effectively caps the amount of Permanent Ag Land. (Hectares)

Change in Rate of Ag Production = The annual change in the rate of agricultural productivity. (Fraction/year)

Current Rotation Length of Shifting Ag Land = How many years do farmers cultivate shifting agricultural land before retiring it to fallow. (Years)

Target Rotation Length of Shifting Ag = If the project changes the length of time that shifting agricultural land can be cultivated before returning to fallow, then we have to input the target number of years. LUCS assumes that the increase in cultivation time will not be instantaneous. Therefore, input the yearly increase in adoption of the new technology in the variable Fraction Increase in Adoption of New Technology. For example, one project increased the cultivation time from 2 years to 8, by encouraging the use of green cover crops through extension services. But the complete change will take about 5 years to complete. Therefore the Fraction Increase in Adoption of New Technology was equal to .2 or 20 percent per year. If the project will not effect the length of cultivation then input the same number of years for Target Rotation Length of Shifting Ag as you input for Current Rotation Length of Shifting Ag Land. (Year)

Fraction Increase in Adoption of New Technology = If the project changes the length of time that shifting agricultural land can be cultivated before returning to fallow, then please input the yearly rate of adoption of the new agricultural practice. (Fraction)

Degradation of Shifting Ag = The fraction of shifting agricultural land which after its cultivation period can not return to production. The Degradation of Shifting Ag converts the fraction input from Shifting Ag to Grazed or Degraded Land either due to soil degradation, for example, or if the land is converted to pasture and not returned to forest fallow. (Fraction)

6. Human-Induced Land Use Conversion

Annual Conv of Open Woodland to Tree Plantations = The number of hectares of open woodland per year converted to tree plantations. The activity will only take place between the Project Start Time and the Project End Time. (Hectares/year)

Initial Rate of Closed Forest Converted to Tree Plantation Cat 1 = What is the fraction of closed forest that is converted to tree plantations? (Fraction)

Growth Rate in Conversion of Closed Forest to Tree Plantation Cat 1 = What is the growth rate in converting closed forest to tree plantations. (Fraction/year)

Desired or expected Conversion of Agroforestry to Tree Plantations = What will be the number of hectares per year of agroforestry converted to tree plantations. (Hectares)

Time Required to Convert Agroforestry to Tree Plantations = How many years to convert agroforestry to tree plantations? (Years)

Desired or expected Conversion of Grazed or Degraded Land to Tree Plantations = How many hectares per year of grazed or degraded land will be converted to tree plantations as a result of human induced activities? (Hectares/year)

Desired or expected Conversion of Degraded Land to Agroforestry = What will be the rate of conversion of grazed or degraded land to Agroforestry forest? (Hectares/year)

Desired or expected Conversion of Degraded Land to Restored Forest = What will be the rate of conversion of grazed or degraded land to restored forest? (Hectares/year)

Desired or expected Conversion of Shifting Ag to Agroforestry = What will be the number of hectares per year of shifting agriculture converted to agroforestry? (Hectares/year)

Desired or expected Conversion of Permanent Ag to Agroforestry = What will be the number of hectares per year of permanent agriculture converted to agroforestry? (Hectares)

7. Wood Product Use

Fraction of Tree Plantations Cat 3 Harvest Used for Permanent Uses = What fraction of the wood taken off of Tree Plantations Aging Category 3 will be used for permanent uses such as lumber, fencing or poles as opposed to consumptive uses such as for fuelwood. Limbs, roots, damage and waste should be excluded from the fraction. (Fraction)

Fraction of Tree Plantations Cat 2 Harvest Used for Permanent Uses = What fraction of the wood taken off of Tree Plantations Aging Category 2 will be used for permanent uses such as lumber, fencing or poles as opposed to consumptive uses such as for fuelwood. Limbs, roots, damage and waste should be excluded from the fraction. (Fraction)

Fraction Of Closed Forest Cut for Permanent Uses = The fraction of harvested wood which is used for permanent uses other than being burned as fuelwood. Permanent uses include lumber, fencing, or poles. (Fraction)

Useful Life of Wood Products = Estimate the life of wood products based upon their use. Wood for housing has a longer useful life than poles for fencing. The predominant use of the harvested wood should be used to estimate the useful life. (Years)

8. Forest Management

a) Natural Forest

Protected Closed Forests = How much of the closed forest is protected, thus effectively blocked from changes in land use and logging activities? This variable can also capture closed forest which is unable to be converted to other land uses due to inaccessibility due to slopes, for example. (Hectares)

Selective Cutting of Closed Forest Degrading into Open Woodland = This variable typically represents the number of hectares per year of closed forest where harvesting degrades the forest into lower-biomass open woodland. However, any cause of degradation can also be represented

by this variables such as pest outbreak or damage from pollution. The degradation may result in a break in the continuous canopy or the soil becoming unable to support a closed forest. (Hectares/year)

Growth Rate in Selective Cutting of Closed Forest = What is the rate of change in degradation of closed forest conversion to open woodland. (Fraction/year)

Persons Supplied Per Ha of Managed Forest Offtake = The number of people per hectare who are supported by forest offtake. This may include timber and nontimber forest products. If an expected intervention increases the number of people supported then the project will decrease the amount of required agricultural land because they can purchase food from income earned from forest management. (Persons/hectares)

Maturation Time for CF1 = How long does it take for closed forest Aging Category 1 to mature into Closed Forest Aging Category 2? This variable can also be used to highlight the difference between conventional logging versus sustainable or reduced impact logging. Under Managed Logging the harvest results in Mature Closed Forest being converted to Closed forest Aging Category 2, while under Unmanaged Logging Mature Forest is converted to Aging Category 1. The Maturation time under the With and Without project scenario may be different if the Unmanaged Logging damages the forest so that it will take more time to recover. (Years)

Maturation Time for CF2 = How long does it take for closed forest Aging Category 2 to grow into Closed Forest Aging Category 3? This variable can also be used to highlight the difference between conventional logging versus sustainable or reduced impact logging. Under Managed Logging the harvest results in Mature Closed Forest being converted to Closed forest Aging Category 2, while under Unmanaged Logging Mature Forest is converted to Aging Category 1. The Maturation time under the With and Without project scenario may be different if the Unmanaged Logging damages the forest so that it will take more time to recover than if it had been logged using sustainable logging techniques. (Fraction)

Managed Selective Cutting of Closed Forest = There are several options within the LUCS model to represent logging in your project site. One is as hectares per year, which indicates that x number of hectares per year is logged, which is the case with this variable. Or, if logging is not a yearly occurrence, but occurs as a pulse with some time period where no harvesting occurs, then use the Rotational Managed Logging variable as the input. Managed cutting refers to logging which incorporates effort to lessen the negative impact on the logging site -- for environmental benefits or economic ones, so that less younger, valuable species are damaged. LUCS converts mature forest to aging category 2 under Managed Logging. (Hectares/year)

Rotational Managed Logging of Closed Forest = The number of hectares selectively cut of closed forest. Rotational Managed logging converts mature forest to closed forest aging category 2. This type of harvesting means logging does not occur annually, but on a rotational basis with a period where there is no harvest. (Hectares/year)

Rotation Time of Managed Logging of Closed Forest = The number of years between Managed Logging harvests. (Years)

Unmanaged Selective Cutting of Closed Forest = Unmanaged selective cutting refers to the practice of harvesting yearly. Unmanaged cutting is with no effort to mitigate or lessen the destructive impacts of tree harvesting. Unmanaged Selective Cutting converts Mature Closed Forest to Closed Forest Aging Category 1. (hectares/year)

Rotational Unmanaged Logging of Closed Forest = Unmanaged is in contrast to sustainably harvested forest. Unmanaged Logging converts Mature forest to Aging Category 1 in contrast to Managed Logging. This type of harvesting means logging does not occur annually, but on a rotational basis with a period where there is no harvest. (Hectares)

Rotation Time of Unmanaged Logging of Closed Forest = The number of years between Unmanaged Logging harvests. (Years)

Year of First Selective Cut = In the project area and within the time frame of the project, in what year will the first Managed Logging occur. (Year)

Year of First Unmanaged Logging = In the project area and within the time frame of the project, in what year will the first unmanaged logging occur. (Year)

b) Restored Forest and Tree Plantations

Maturation Time for Restored Forest = The maturation time is the amount of time needed for the restored forest biomass accumulation to reach its maximum biomass. (Years)

Maturation Time for Tree Plantations Aging Cat 1 = How many years until the newly planted trees mature into aging category 1? (Years)

Maturation Time for Tree Plantations Aging Cat 2 = How many years until tree plantations in category 1 mature into aging category 2 or secondary growth? (Years)

Maturation Time for Tree Plantations Aging Cat 3 = How many years until tree plantations in category 2 mature into category 3 or become mature trees, ready to be harvested. (Years)

Tree Plantation Harvest Switch = This variable must be zero or one. The switch should equal zero if no harvesting of Tree Plantations occurs, 1 if harvesting occurs. (1 or 0)

Annex 2. Brief Description of Land Use and Carbon Sequestration Model (LUCS)

(All the information in this document was extracted from the LUCS Manual Draft Version, edited by World Resources Institute in July 1996).

Introduction

The model was constructed with three principal considerations:

- Capture the essential physical interactions between people and forests in developing countries.

- Not be overly complicated.

- Be able to represent a wide variety of situations and management schemes.

The principal purpose of the model was to track the implications of different management schemes in widely different areas to evaluate project proposals. The model does not predict prices, incomes or other economic indicators. The user must determine the rates of change for key parameters such as population and agricultural productivity. The model serves as an accounting tool, tracing the implications of these scenarios. Because the nature of the interventions proposed were so diverse (for example, agroforestry, fuelwood stoves, forest management, agricultural extension), and because the model was designed to operate at the project of subregional level, land use is the basis of the model. This places the burden of defining the future on the analyst, and not on the model. LUCS also makes the assumptions behind the carbon estimate transparent.

The LUCS model offers project managers and designers the opportunity to investigate different land use scenarios. The analysis' results could also serve as quantitative evidence of both the project's cost effectiveness and amount of carbon sequestered, which could be useful for verification of contractual compliance and/or fundraising purposes. Additionally, LUCS offers project implementers and planners the opportunity to model project modifications that could increase the cost effectiveness of the project, maximize the amount of carbon sequestered, or increase a particular sector of the project, such as agricultural productivity, or protected forest.

To assess changes in land use over time, we approximated relationships between human population growth, the subsequent need for food and energy, technological change, resource management, and land-use change. LUCS was developed originally to model poor areas that depend largely upon low-productivity agriculture for subsistence and fuelwood for energy. We have modified the model somewhat to widen its applicability, but the basic assumptions are still best adapted to developing regions, where there are multiple forces interacting to drive land use change.

Land use change is primarily driven either by population change or land management. As the population grows, more land is required to supply food and, in some cases, fuelwood. While demand for food grows, the land's ability to meet that demand may increase or decrease depending on changes in productivity and project activities.

Project interventions are compared against a baseline scenario, which simulates the conditions of the project site without the benefit of the project intervention. The difference between the amount of carbon sequestered with and without project interventions is the net carbon sequestered.

The most appropriate use of the model is as a tool for comparing and contrasting both the broad differences between sites and alternative management regimes at a given site. The results that the model produces are in this sense can be qualitative as well as quantitative in nature. I.e., does a given intervention make a minor or major difference in the net carbon result? Different interventions can also be tested to assess their relative effectiveness in producing sustainable land-use patterns in addition to their carbon sequestration potential.

LUCS Model Overview

The model's primary use is at the regional/project level. LUCS is essentially a carbon accounting device which allows the user to ask a series of what if questions, and trace out the implications of various scenarios. The Overview describes what drives land use changes in the model, the underlying structure, and key parameters and variables in detail. The Overview section is divided into the following categories: Population, Land Use and Biomass, Fuelwood, Forest Management and Uses, Forest Harvesting, Agricultural Production, and Project Management.

Population

Changes in land use are determined by population growth, agricultural productivity and its growth rate, and project activities. Since it is assumed that the local people derive most of their livelihood from the project region, increases in population increase demands on the landscape. As the population grows more land is required to supply food and fuelwood. However, while demand grows in absolute terms, its impact on the land base can grow at a lesser or even negative rate depending upon changes in productivity and project activities.

The *rate of population change* slows to zero as the year that the population is expected to stabilize approaches. In this way the model can represent a demographic transition from exponential growth to stability.

Land Use and Biomass

As the name implies, land use is the basis of the LUCS model. The nine categories of land represented in the model are based on principal uses and distinguished by the amount of biomass present. The biomass of each category is constant and represents the average amount of tons of biomass per hectare of that land use type. For example, the tons of biomass per hectare for mature closed forest is clearly not equal on each hectare, so an approximate average of the biomass for the area of closed forest should be used.

The model represents changing biomass levels by movement from one land class to another. Forest degradation, for example, due to loss of biomass for fuelwood, is represented as a movement of land from closed forest to open woodland and then to degraded land. The principal land uses include:

- Three categories of agriculture—permanent, shifting and agroforestry.

- Five categories of forest or woodland—closed, open woodland, tree plantation, forest fallow and restored forest.

- One category combining grazed and degraded land.

The five categories of forest or woodland are subdivided into early, medium and mature age classes to represent growth stages in forest maturation. Biomass accumulation in tree plantations, restored forests and forest fallow is represented by "aging chains."

Carbon sequestration is calculated from standing biomass, wood products and fossil fuel use. *Carbon in standing biomass* is determined by multiplying the area of each land use category by its average biomass then multiplying the sum by the carbon content of biomass.

Carbon in Standing Biomass = Closed Forest*Closed Forest Biomass

- Open Woodland*Open Woodland Biomass

- Permanent Ag Land*Permanent Ag Land Biomass

- Tree Plantations Aging Cat 1*Tree Plantation Biomass Aging Cat 1

- Tree Plantations Aging Cat 2*Tree Plantation Biomass Aging Cat 2

- Tree Plantations Aging Cat 3*Tree Plantation Biomass Aging Cat 3

- Shifting Ag Land*Shifting Ag Land Biomass

- Agroforestry Land*Agroforestry Land Biomass

- Grazed or Degraded Land*Grazed or Degraded Land Biomass

- Forest Fallow Cat 1*Forest Fallow Biomass Cat 1

- Forest Fallow Cat 2*Forest Fallow Biomass Cat 2

- Forest Fallow Cat 3*Forest Fallow Cat 3 Biomass

- Restored Forest Aging Cat 1*Restored Forest Aging Cat 1 Biomass

- Restored Forest Aging Cat 2*Restored Forest Aging Cat 2 Biomass

- Restored Forest Aging Cat 3*Restored Forest Aging Cat 3 Biomass)

- Carbon Content of Standing Biomass

Fuelwood

A preference for fuelwood over fossil fuels such as kerosene is assumed. Fossil fuel is used when demand for fuelwood exceeds the local supply. The carbon released from the stock is added to the total carbon sequestered as a negative value.

Fuelwood requirement is determined by population and the *fuelwood requirement per person*. The fuelwood requirement can be reduced if there are efficiency improvements from fuelwood stoves. These efficiency improvements depend on the addition of stoves, the fuelwood savings from stove use, and average family size, which determines the number of people affected by the use of a single stove.

Two main sources of *available fuelwood* are captured in the LUCS model: 1) fuelwood available from land conversion that is destructive (i.e. where there is enough biomass loss to result in a change of land use type); or 2) fuelwood available from collection or harvest that is non-destructive. Fuelwood collection from closed forest and open woodland debris is a small fraction of the biomass of these two categories multiplied by their respective area. Fuelwood from agroforestry is calculated in a similar manner, but the fraction of wood collected is much higher. Agroforestry systems are often designed to produce large biomass harvests from trees that regrow.

As forested land is converted to agricultural uses, large amounts of biomass are destroyed. People can make use of this biomass for their fuelwood needs. The model calculates the fuelwood available from destructive clearing as a fraction of the rate of land converted multiplied by the difference in biomass between the two categories.

In extreme circumstances, fuelwood deficits can result in forest degradation and loss. This possibility occurs in the model when the available fuelwood (last year) was less than the fuelwood requirement. If there was a deficit in the last year, this is made up by destructive fuelwood harvesting. The rate of conversion is a determined by the size of the previous fuelwood deficit, the fraction of land converted from open woodland which is the ratio of open woodland to total natural forest, and the difference in biomass between open woodland and grazed or degraded land. If the fuelwood deficit is 10,000 tons, the fraction of open woodland to natural forest 0.25, and the biomass of open woodland and grazed or degraded land 125 and 25 tons per hectare, respectively, then the area of open woodland converted to grazed or degraded land from destructive fuelwood collection will be 25 hectares (10,000 * 0.25)/(125 - 25).

The remainder of the fuelwood deficit will come from closed forest conversion to open woodland, calculated in the same way. Closed forest conversion is limited to the unprotected area. Closed forest can also be converted to open woodland from logging and that open woodland can revert to closed forest over a given period of time.

Forest Management and Use

The model tracks wood harvested for permanent uses, e.g. lumber, fencing, poles, etc. This wood comes from the harvest and thinning of trees in the closed forest, open woodland and tree plantation categories. The area harvested is multiplied by the biomass and the fraction of biomass that goes into a permanent use. Limbs, roots, damage and waste should be excluded from the fraction. The variable, *useful life of wood products*, is based upon their use. Wood for housing has a longer useful life than poles for fencing. Usually there will be a mixture of uses and it is best to use an average. Of the approximately ten projects modeled using LUCS, twenty years was value most often given as the *useful life of wood products.*

Harvest from tree plantations can be both destructive and non-destructive. As tree plantations mature, they need periodic thinning to produce optimal growth. The thinnings produce biomass that can be used for fuelwood or more permanent uses such as poles. At maturity, tree plantations are cleared and replanted. The harvest, once again, can be used for fuelwood, timber, pulpwood, or other uses. In the model, tree plantations are represented as an aging chain. The available fuelwood is calculated as a fraction of the total biomass (average biomass by area) maturing or being harvested for each aging category. The fractions may be large if the plantation is intended solely as a fuelwood source, zero if it is not, or something in between if, for example, the trunks are used for timber and the branches for fuelwood.

Forest Harvesting Practices

A common harvesting practice employed in tropical forests is selective logging, the successive removal or "high grading" of the largest trees. If the forest is not allowed to fully recover before the area is logged again, the forest can be seriously degraded in terms of species and biomass. Three types of logging are represented in the LUCS model: 1) logging that removes sufficient biomass to result in a change in the character of the forest (i.e. closed forest to open woodland, as described above), *Selective Cutting of Closed Forest Degrading into Open Woodland*; 2) selective logging (both annually and on rotation, see below for variable names) and 3) regeneration management, characterized by clear cuts followed by replanting and thinning (*Initial Rate of Closed Forest Converted to Tree Plantation 1*).

The model structure for the calculation of closed forest biomass under selective logging can be represented as follows:

The basic structure is an aging chain, wherein three aging categories are represented. Aging category 3 represents mature closed forest with the maximum biomass attainable for the area. Aging category 1 is the minimum biomass while still having a closed canopy. Aging category 2 is the approximate midpoint.

The three levels of tree plantations represent the aging of a woodlot. As the trees mature, the appropriate amount of land is transferred to the next age class. The aging chain represents the S-shaped growth curve.

Each forest system's (tree plantations, closed forest, restored forest) growth pattern is represented by the three aging categories. The third category represents the mature forest, the first category is the minimum biomass required to remain in the forest category and aging

category 2 is the average of the first and third categories. This method approximates volume growth for those categories that require it.

Unmanaged logging, represented by the variables *Unmanaged Selective Cutting of Closed Forest* and *Rotational Unmanaged Logging of Closed Forest*, moves land from aging category 3 to aging category 1. However, if logging incorporates natural forest management techniques, then logging (*Managed Selective Cutting of Closed Forest* and *Rotational Managed Logging of Closed Forest*) moves land from aging category 3 to aging category 2. As the forest matures area is moved to category 2 and then 3. As long as the annual selective cutting does not exceed the rate of maturation, the biomass will be maintained. Degradation occurs when selective cutting exceeds maturation of immature categories. In that case more land is moved to categories 1 and 2, increasing their predominance and reducing the average biomass. Over time, as the forest in aging category 3 is depleted, forest in aging category 2 will be cut.

An alternative system of management used in some tropical areas is regeneration cutting. In this system closed forests are cut over, leaving a few mature individuals, as seed sources for regeneration. Periodic thinning keeps increases the rate of maturation. This system is, in practice, much like the management of a tree plantation, and has been represented in this way in the model. As closed forest is harvested, land moves into the first tree plantation aging category, maturing and remaining in that use. Similarly, land can be moved into tree plantation management from open woodlands.

Agricultural Production

Required agricultural land is a function of *population*, *agricultural land required per person*, *fraction of food imported* and agricultural land required for export production. Agricultural land per person is a variable that captures the productivity of the project region. Areas of low productivity require more agricultural land to support the population and export production. The value of this variable changes over time according to the estimate given for *growth rate in agricultural productivity*.

Agricultural land requirements are reduced by the *fraction of food imported* into the project area and increased by the amount of land used for export production and its rate of growth.

There are three broad types of agriculture specified in the LUCS model: permanent, agroforestry, and shifting agriculture. This disaggregation is necessary to capture principal differences in cropping, fuelwood production, associated land use, and average biomass. Permanent agricultural land as used here can be thought of as continuously cropped land. Agroforestry is another type of permanent cropping, but these sorts or systems are mixed with perennials and commodities produced may include a crop used as fuel and typically have a greater amount of biomass. Shifting agricultural land is not continuously cropped, but rather is put into fallow after some period of cultivation. At the end of the fallow period the land is either returned to cultivation, or eventually returns to forest.

Each of these three categories of agricultural land is characterized by its own level of productivity. In the LUCS model productivity is defined as the amount of land required to support one person. More productive systems of production can support more people on a given

unit of land. The productivity of agroforestry and shifting agriculture should be defined in relation to permanent agriculture. For example, one project, which helped set up community nurseries to encourage agroforestry, the project developers estimated that agroforestry was one and one half times more productive than permanent agriculture.

Therefore the variable, *ratio of productivity of agroforestry to permanent ag*, would equal 1.5.

In order to determine if the amount of agricultural land at any given time is sufficient to meet local and export requirements, the model multiplies the area of each category by its respective productivity ratio (1 for permanent agriculture). These are summed to determine the total amount of agricultural land, which is compared to the required agricultural land to determine the *agricultural land shortfall*. Required agricultural land is estimated one year in advance, so there will be a shortfall as long as population is growing.

An agricultural land shortfall results in the movement of land to agriculture. Land can be moved to agriculture from: 1) conversion of closed forest, 2) conversion of open woodland, and 3) reversion of forest fallow (See Figs 2 and 8). The rate of conversion is indicated by the relative amounts of open woodland and closed forest, the agricultural land shortfall, and the fraction of new land brought into permanent agriculture. Limits are placed on the conversion, as no more open woodland can be converted than exists, and no more land can be put into permanent agriculture than is suitable for that type of production (*maximum permanent agricultural land*). The time required to convert agricultural land is assumed to be one year in order to match projected with actual requirements.

If an agricultural land shortfall exists, and no more land can come from forest fallow, then open woodland or closed forest will be converted to agriculture. When open woodland is converted, the *fraction of land converted from open woodland* is the amount of open woodland divided by the area of open woodland and closed forest. The model assumes a spatially even landscape and directs conversion by the relative availability. For example, if there were 900,000 hectares of closed forest and 100,000 hectares of open woodland, then the fraction for conversion would be 0.90 and 0.10, respectively, for closed forest and open woodland.

The conversion fraction is multiplied by the agricultural land shortfall and a constant that indicates the fraction of new agricultural land that is normally brought into each agricultural land type. The user must determine the initial fraction of land brought into production for each agricultural land type: permanent agriculture, shifting agriculture and agroforestry. The variables: *Initial Fraction of Land Brought into Permanent Ag Production*, *Initial Fraction of Land Brought into Shifting Ag Production*, and *Initial Fraction of Land Brought into Agroforestry Production* must sum to one.

For example, if an area consists of 75% shifting agricultural land and 25% permanent, the parameters would be: *Initial Fraction of Land Brought into Shifting Ag Production* = .75, while *Initial Fraction of Land Brought into Permanent Ag Production* =.25. This means that if an *agricultural land shortfall* exists, and forest is converted to agriculture, then 75% of the forest is converted to shifting agriculture, while 25% is converted to permanent agriculture. As conditions change, for example if the maximum amount of permanent agricultural and is reached, these fractions effectively change. Also, the project may impact the proportions, via the variables,

Change in Fraction of Land Brought into Agroforestry, Permanent Agriculture, and Shifting Agriculture.

This same structure is used for conversion of open woodland and closed forest to permanent agriculture, agroforestry and shifting agriculture. However, for closed forest, the variable, *protected closed* forests, represents the effective protection of parks and places a constraint on the conversion to agriculture. Also, if closed forest is on steep slopes, or is otherwise made too difficult to cultivate or harvest, then that land should also be counted as *protected closed forests*. Only *unprotected closed forest* can be converted to agricultural or other categories.

Shifting agriculture, because of its use of fallow, has a more complicated structure than permanent agriculture or agroforestry. As in the other two categories, land can be converted from closed forest or open woodland to shifting agriculture. In addition, shifting agricultural land can be converted to agroforestry through project activities, or degraded to a low biomass category called grazed or degraded land.

The fallow period, named *time for forest fallow to return to cultivation*, may be twenty years or more, during which time the fallowed land can accumulate significant amounts of biomass. For this reason, the forest fallow category is split into three age classes to capture the biomass dynamics. After a given cultivation period, *rotation length of shifting ag land*, typically in the range of 2 to 8 years, shifting agricultural land moves into the first aging category of forest fallow. The maturation time to the next age category is one-third of the total fallow period.

At the end of the fallow period the land returns to cultivation if an agricultural land shortfall exists. If no shortfall exists, the third aging category reverts to open woodland or closed forest. In the event that the agricultural land shortfall is larger than the amount of land that will be moving into shifting agriculture from the third forest fallow age category, more land will be returned to production from the second age class.

Project Management

There are many strategies for modeling your project s effects on the region, either through increases in agricultural productivity, or improvements in harvesting regimes, just to name a few examples.

The Project Management variables are those variables which typically represent direct project activities, such as the dissemination of additional fuelwood stoves, rather than project effects.

Areas that have previously been degraded are often considered for ecological restoration. These areas may additions to national parks, or areas within parks that have been subject to clearcutting and grazing. The model has a special category of land use called restored forests to capture this. The restored forest matures over a period determined by the ecological characteristics of the site. The maximum biomass accumulation is assumed to be the same as that for closed forest. Since significant investments are required to restore degraded land in this fashion, the assumption is made that further efforts will prevent the conversion of this land back to other uses.

Another option for converting grazed or degraded land is *desired conversion of degraded land to agroforestry*. Several projects have conducted outreach to encourage agroforestry on grazing

land, basically encouraging tree planting on grazed, or previously grazed land, to increase biomass, provide animal fodder and fuelwood, and help recuperate the soil.. The other variables on the **Project Management Screen**, include providing fuelwood stoves, which was discussed in the fuelwood section, and converting shifting and permanent agriculture to agroforestry.

Annex 3. GEOMOD2: A Spatially Explicit Land Use Change Model

Model Structure

GEOMOD was developed by researchers at the SUNY College of Environmental Science and Forestry (Hall, et al. 1995a; 1995b) with funding from the US Department of Energy, Carbon Dioxide Research Program, Atmospheric and Climatic Change Division. The model predicts the location of land use change. The rate of change is derived by comparing the area of forest found in a map of land use at one point in time to that found in another at a different point in time. A future rate of change can also be estimated from predicted population growth or economic activity, or a combination of the two, if we do a regression analysis of the relation of the area of undisturbed land converted during a time step (e.g. 1 year, 5 years, or one decade) to the corresponding population and economic growth, or decline, over that same period.

The second prediction, location of that estimated land use conversion, uses a statistical deduction approach to analyze historical patterns of land use change against user-supplied map layers of bio-physical and cultural attributes. The change observed in any given landscape 'cell' is analyzed against a number of candidate drivers, which researchers have determined as potentially the most important factors influencing human settlement patterns. GEOMOD2 essentially uses non-linear multiple-regression to weight each driver according to its assessed importance in determining the pattern and location of changed cells over time. The underlying philosophy is based on the "maximum power principle" (Odum 1983). It is assumed that those conditions which are most likely to significantly impact an individual's energy return on investment (EROI) (Hall, Cleveland and Kaufmann 1986) as he/she develop and work new ground include such variables as: topographic position (elevation and steepness of slope), distance from rivers, roads and already established settlements, climate variables, etc. Each of these variables can affect the energy cost or the expected return from a development decision. In other words we assume that developers are knowledgeable to some degree about where development would be most profitable in energy and hence economic terms. Using the assigned weights, GEOMOD can then develop or undevelop land going forward or backward in time. Starting from seeds of earliest development it extends human activity across the landscape, creating a pattern of development from undisturbed to disturbed that closely mimics reality. As it 'nibbles' away at the landscape the model adheres to the three following principles: (1) adjacency, which is the tendency to develop land next to land already developed; (2) dispersion, which is the phenomenon to 'jump' from one place to another relatively favorable location; and (3) regional heterogeneity, which accounts for significant differences in the pattern and rates of land use change among subregions or countries because of the population density, economic and political factors particular to those places.

Data Requirements

The model is FORTRAN-based and requires as inputs a spatially-referenced set of equally-dimensioned digital grid (raster) maps. For this project, the following inputs, at a minimum, are required.

1. A digital elevation model, or better yet, a digital coverage of elevation contours and maximum/minimum elevation points from which a DEM can be prepared using ARC/INFO's (ESRI) Tin generator. Slope and aspect, potentially important drivers, are derived from this.

2. A digital hydrography coverage (streams, lakes) also used to generate the DEM.

3. A digital coverage of roads

4. A coverage of any other transportation routes (rail, air, boat) that give people access to the interior.

5. Classified and geo-referenced land use maps derived from either aerial photography or satellite imagery for preferably two points in time, and preferably at the same scale and no smaller than 1:24,000 with a grid cell resolution no larger than 30 x 30 meters. Existing settlements should be one of the identified land use classes. Also any land guaranteed as 'set aside' (i.e. protected) should be indicated (see summary below).

6. Population data over the same period of time.

7. Climate data, particularly if there is a considerable elevation gradient. These would include both mean annual temperature, mean minimum and mean maximum and precipitation measurements from one or more nearby weather monitoring stations, if available. (The elevation and geographic coordinates of that station are required as well.)
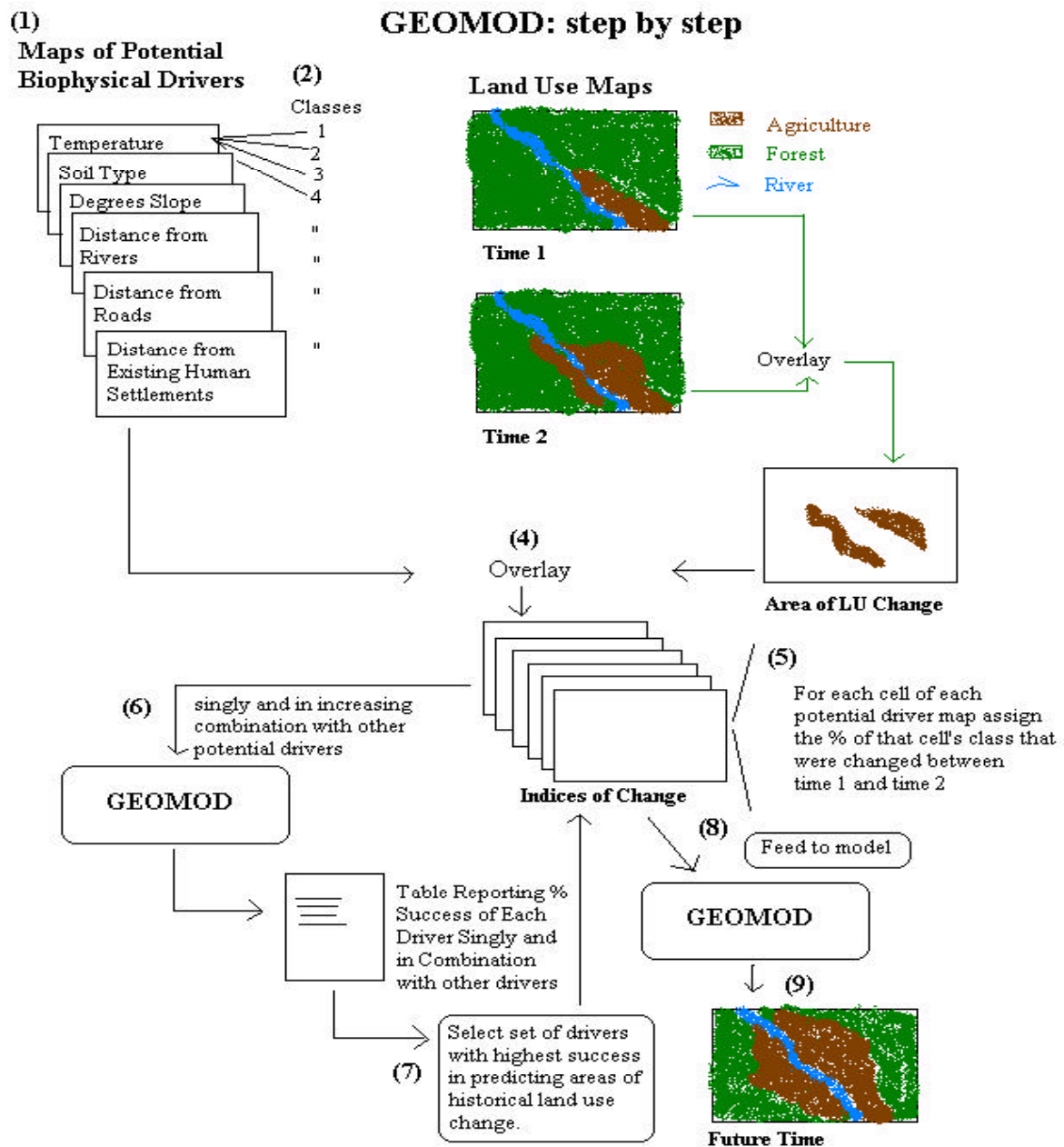
Figure 1. GEOMOD: step by step

Additional useful data:

8. Economic data such as crop production, investments, or exports.

9. A digital soil map and accompanying information on such soil characteristics as soil thickness, drainage characteristics, annual flooding, infiltration rate, % silt, clay, loam.

10. Any other climatic data, PET, daily insulation, cloud cover, etc. could be useful.

11. Biomass estimates for digitized vegetation polygons, or, if the land use map is classified at a level that supports biomass estimates, then an accompanying table would be useful.

Methods

I. *Reclassification of Land Use Types*

A. GEOMOD can evaluate change in two land use types at a time. Therefore, each map of land use change must be reclassified similarly. The most common reclassification is to classify all undisturbed forest as type 1, and all other land use types, which can be characterized as having undergone some human intervention, such as urban and agricultural areas, as type 2. In addition, land that will not be evaluated, such as land that is unlikely to ever be used by humans for productive activity, e.g. deserts, can be excluded from the analysis. Normally in the original land use map these areas are assigned a unique value. Furthermore, land that sits within the grid map, but lies outside the area being modeled, also must have a unique identifying number, indicating that it will not be included in the evaluation. This could include land in another country or region, oceans, or areas for which no data exists. A normal land use map, ready for input to GEOMOD, therefore, will usually consist of four possible values as follows:

1 = forested

2 = agriculture, cities, pasture, degraded land

3 = deserts, water (lakes, oceans, rivers)

4 = outside region of interest

II. *Rate Estimation*

A. If two maps of land use from two points in time are available they must be reclassed as shown above. Using an area calculation we can determine how many cells of forest existed in each period. Subtraction of the second from the first tells us how many cells were deforested in the interim period. This number times the area per cell yields total area deforested. When we divide the area by the number of years we have our rate per year.

B. We can also calculate the rate of deforestation per year as a function of population or economic growth. Linear analysis of deforestation versus population, or multi-linear regression of deforestation versus population, gross regional product, exports, agricultural

production, etc., allows us to project different rates of growth according to these indicators and hence simulate the land use change that can be expected as a function of changes in these independent variables. This gives us more flexibility to test different future scenarios.

III. *Setting up the 'SET' files*

Before running GEOMOD the user must prepare two input files which provide important information to the program. These are called GEOMOD.SE1 and GEOMOD.SE2. The former provides information on the number of time steps, the beginning and end years, the names of the input maps, their format, the types of land use categories, and the driver weights.

Products

GEOMOD will produce a time series of land use maps, at a time interval to be selected, over the 40-year life of the project. Each digital map will be produced as a color print, and the area in each land-use type will be reported in an accompanying table. Additionally, the output and accompanying predicted data, can be displayed in a time-series display module called ECOPLOT (RPA 1997). ECOPLOT displays the changing landscape, over time, as a central image, and graphs important driving variables, and program output as graphs surrounding this image (e.g. population growth, GDP, linear miles of roads built, biomass, carbon stored in the vegetation, etc.) (See http://www.mesc.usgs.gov/glacier/glacier_model.htm (Hall, M. 1995) for a 'virtual' example of ECOPLOT displayed on the USGS web site – minus the graphs described above.) This tool is particularly intuitive for illustrating rapid and significant landscape change and is a useful informational aide when presenting land use alternatives and decision-making options, and their environmental consequences, to politicians, resource managers, developers, financial backers, and the general public.

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Annex 4. Deforestation Modeling

(This material is taken from W. Marzoli prepared for the EPA co-op project)

Introduction

The deforestation model presented here was first formulated in the framework of the FAO Forest Resources Assessment Project (FRA 1990) implemented during 1990–94 [i] [ii]. The scope of the Project was to appraise the state of tropical forest resources for the reference year 1990, and to estimate changes during 1980–90.

The need for a deforestation model became apparent during FRA 90, since the majority of the tropical countries were lacking multi-temporal information on forest cover. To solve the problem, research was undertaken to develop an estimation procedure [iii], such as a modeling approach, which could produce the required change information for all countries. The basis would be multi-date observations for a limited number of countries, in combination with another set of correlated variables for which data were available for all countries. This chapter reports the findings of the model and the values of coefficients of the estimation process, based of the latest revision of the model carried out in year 1998 [iv].

Detailed motivation for using a scientific approach in FRA 1990 is given in the FAO Forestry Papers 112 and 124. The project began by collecting all the available information produced by forest inventories in developing countries. This material was then critically reviewed and organized into a database. The classification scheme of each inventory was carefully analyzed to make the necessary adjustments to conform to the common standard required by the global assessment. Within FRA 1990 the definition of forest accepted for tropical developing countries was "ecosystems with a minimum of 10% crown coverage of trees and/or bamboos, generally associated with wild flora, fauna and natural soil conditions, and not subject to agricultural practices". As a general rule it was not possible to define a perfect match of original inventory classes of the countries to the defined standard: very open forests, shifting cultivation and tree savannah are all examples of classes that can include area falling outside standard forest definition. Expertise and knowledge of local conditions was used to decide on the inclusion or exclusion of such classes, or part of classes, on a case by case basis.

The collected data were disaggregated on a sub-national basis, administrative boundaries of different kinds, e.g. state, region, province or district, were defined and identified in the project's geographic information system, particularly for larger countries. In all over 600 geographic units are defined for tropical developing countries and more than 1,000 for all developing countries. In addition whenever possible not only single date forest cover data were collected but also forest cover time series. It was found that for 85 geographic units time series of two or more dates were available. This data set constituted the basic units for analyzing the rate of deforestation. In particular the existing forest cover time series were the basis for model construction. This approach, by reducing the size of the elementary geographic units, makes within-unit variability

smaller and leads to a detailed data set with more accurate information and closer relations among interacting factors.

Model building

Background

Deforestation, in context of this analysis, results from the expansion of the non-forest area, that is to say, from human activity exploiting forest area as a non-renewable natural resource. The causal analysis of the deforestation in the tropics involves a complex system of inter-relation resulting from the effect of different driving forces, some accelerating deforestation, others slowing deforestation.

In building this model it was decided, based upon some preliminary statistical analysis, to test the hypothesis that the overall pattern of expansion of non-forest area over time would be described by an elongated "S" shaped or logistic curve. The model was developed interpreting the man / environment interaction as a biological growth process. Very much like biological growth processes deforestation was observed to increase relatively slow at initial stages, much faster at intermediate stages, and slow down at final stages.
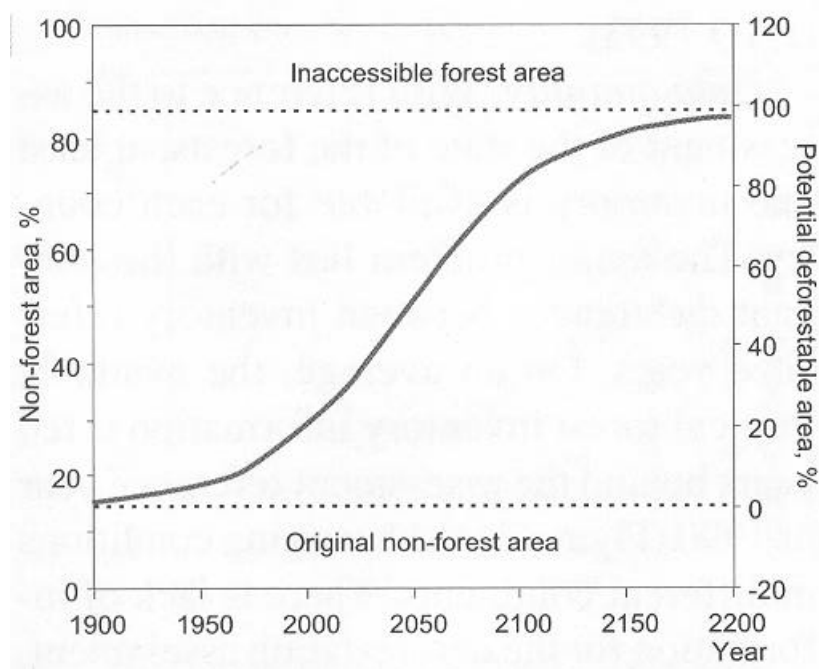
In the case of non-forest area expansion, the processes characterizing initial development phases that contribute to the expansion include, e.g. continuously growing demand for new agricultural land, and increase of exploitation capability due to previous exploitation achievements. A typical example of this pattern of expansion was observed for instance in Brazilian Amazon.

Processes contributing to the declining phase include: progressive decrease of forest area accessibility, and technological developments affecting intensification of agriculture or the capability to use other resources, e.g. shifting from fuel wood to other energy resources.

When tracing the history of non-forest area expansion back to the origin, if it was possible, different countries would be expected to undergo similar "S" shaped patterns, but displaced in the time and height depending on the local environmental conditions and historic development. If reliable time series where available for many countries in the tropics, well known and robust analytical methods could be applied. Unfortunately, as already stated, this is not the case.

Given the constraints of the available time series data, a cross-sectional approach was necessary to pool the available data. Grouping together countries or other geographic units at different development stages, but otherwise in comparable conditions, should result in some indication of how non-forest area expands under the giving conditions.

In order to have a common scale for units for varying size, it is necessary to consider the stock variable relative values such as the ratio of non-forest area to total area or non-forest percentage values. Initial values might be greater than 0% if some part of the unit had no potential forest cover even before any deforestation took place (major water bodies, deserts, alpine conditions, etc.). Final values might be limited under 100% by total inaccessibility conditions. Thus, considering the potential deforestable area as the ratio denominator for non-forest area density evaluation would, where possible, constitute a more accurate choice for the stock variable. If it is not possible, the total land area of the unit could be used as the ratio denominator (Figure 1).

Figure 1: Non-forest area and potential deforestable area


Role of population

In the logistic interpretation of non-forest area expansion, the stock variable is expressed as a function of age rather then absolute time. Age should measure the time elapsed since the process initiation time t_0, but it is unpractical to identify effective t_0 values for each geographic units. In countries that have experienced intensive development in historical times (generally), deforestation took place centuries (Europe) or millennia (China) ago. Where human settlement is more recent, deforestation occurred in recent times and is still occurring today.

Moreover non-forest expansion is not a natural or biological process but rather a human society development process. Therefore it is closed related to demographic factors. Almost all tropical countries experience relevant increases in population and this is expected to continue for quite some time in the future.

For any given geographic unit, within the range of years when population is monotonously increasing, time is the single valued function of population. Within these limits, the population dimension constitutes an effective expression of age for analysing the area expansion of non-forest land. Again, to account for the variable size of geographic units, population density values are considered rather than absolute values. In addition a better correlation between population and forest cover was found using a logarithmic transformation for population density. Actually the variable used in the model was log(population density + 1) to avoid negative values for geographic units where population density per square kilometre is less than 1.

Applying the theoretical frame described above to the observed multi-temporal observations of forest cover the following overall trend was observed (Figure 2).

Figure 2: Non-forest area and population dimension in available time series from reliable forest inventories
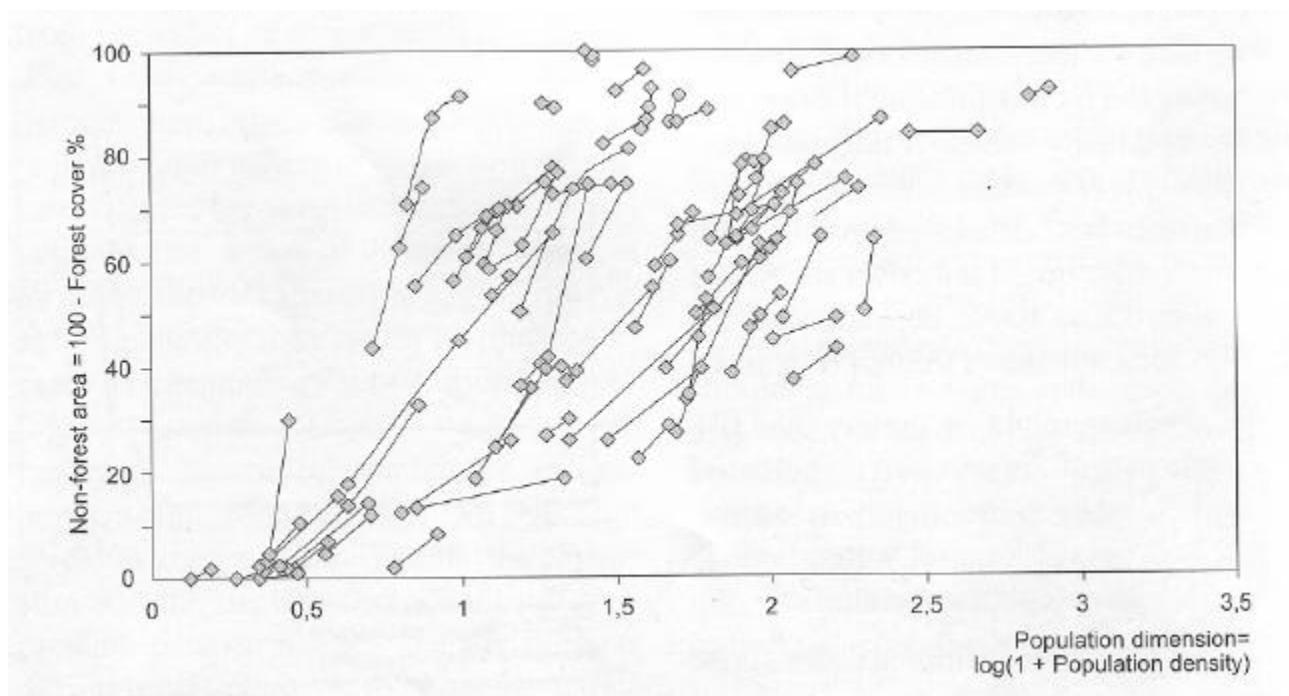
Ecological zoning

Having identified age and stock variable expressions that, to some extent, reduce differences among geographic units due to size, potential deforestable area and deforestation initiation time, different "S" shaped patterns are still expected. The ecological conditions, for example, are expected to have a relevant influence. Consider, for instance, the deforestation due to demand for new agricultural land. Given the strong implications of the ecological conditions concerning the agricultural production system, a higher deforestation rate is expected to take place in areas where more extensive methods are applied due to natural conditions. Another ecological factor influencing deforestation is the suitability for human society development. For instance very humid conditions are less favorable due to pest and disease incidence.

Figure 3 illustrates the basic framework for tropical deforestation modeling that resulted from this analysis. This is referred to as a basic framework as it is considered to be just a starting point for the analysis.

Figure 3: Basic framework for deforestation analysis, including ecological zones
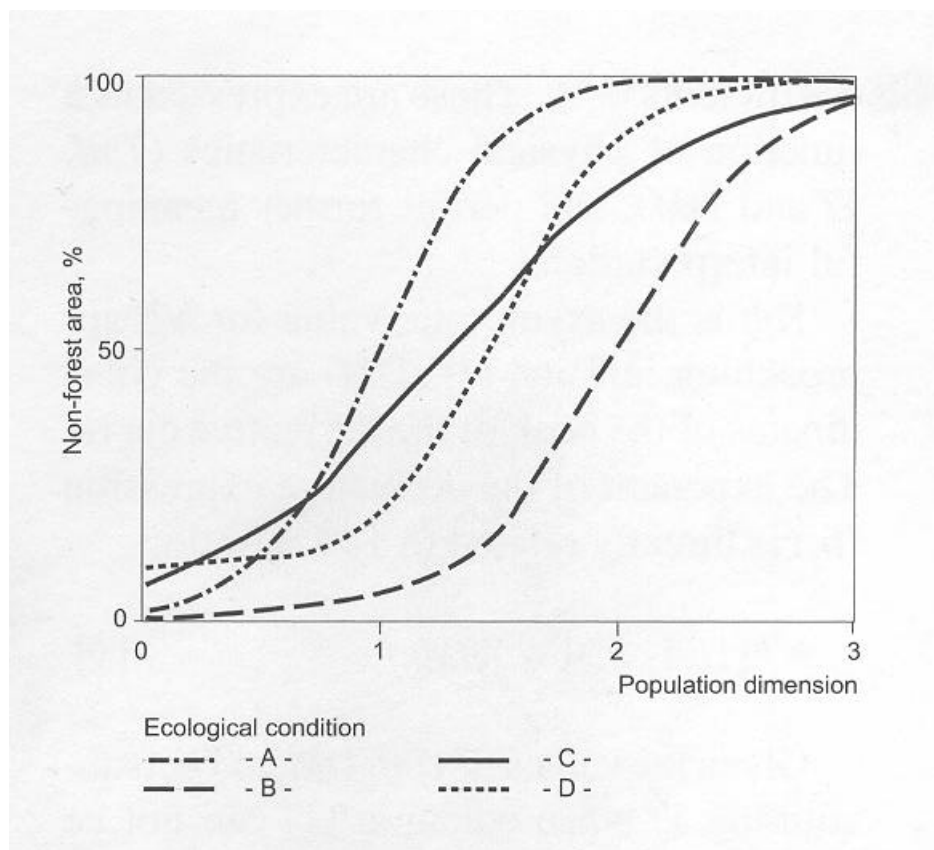
This basic assumption has been tested using an ecological data set containing the proportion of total land area of each geographic unit by ecological class. This information was derived by overlaying the eco-floristic zones map over the geographic unit map. The eco-floristic zones maps are based on ecological and floristic classification of the forests and cover all the three tropical regions. The original classes in each region have been consistently grouped together based on two main characteristics: topography (elevation) and climate (precipitation and seasonality) into the following 12 classes (Table 1).

Table 1: Tropical ecological zones

Class	Elevation	Precipitation regime
1	Lowland	Wet
2	Lowland	Very moist
3	Lowland	Moist with short dry season
4	Lowland	Moist with long dry season
5	Lowland	Sub-dry
6	Lowland	Very dry

Class	Elevation	Precipitation regime
7	Lowland	Desertic
8	Premontane	Moist
9	Premontane	Dry
10	Montane	Moist
11	Montane	Dry
12	Alpine	

Model structure

Combining together observed forest cover time series, demographic time series and ecological settings it was possible to formulate a general model based on the Chapman-Richards growth function, which was well suited to the purpose.

Change model

Equation 1: Change model

$$dY/dp = b1 * Y^{b2} - b3 * Y \quad (1) \; \textit{Change model}$$

In our case

Y is defined as percentage of non forested area

Y = ((Total area) - (Forest area))/(Total area) *100

dY/dp = derivative of Y with respect to population density

b1, b2 and b3 are parameters.

The Change Model structure can be briefly describes as follows:

(i)   **dy/dp** : Dependent variable. It is the ratio between population change and forest area change. It can be represented as the response 'dy' to a given change of population pressure 'dp'. The higher the value of the ratio (dy/dp), the higher the change of forest cover per population change. dy/dp is a function of the 'size' of the forest (Y in Equation (1)) and of the following parameters:

(ii)   **b1** : The effect of b1 on the ratio (dy/dp) is illustrated in Figure 4. This parameter can be represented by a productivity index, or site quality to follow the analogy with yield modeling. In

fact in the present model formulation it is a function of bio-climatic parameters. The value of b1 is determined by the parameter DM that represents the derivative maximum. DM represent the maximum level of non-forest increase per unit population increase. In other words, the same population growth rate has different effect in different ecological conditions.

(iii) **b2** : This parameter represents the culmination point of the derivative function. In the State Model curve (Figure 5) it is the inflection point of the curve, where deforestation rate culminates and start to decrease.

(iv) **b3** : This parameter is related to the maximum possible deforestation (Ym) representing the asymptotic value of Y where an increasing level of population has no effect on forest cover which remains stable in time. This parameter can be related with accessibility, both physical and legal, of the forest resources and to land suitability of forest areas for transfer to other land uses.

State Model

Integration of the differential equation (1) leads to the *Chapman-Richards function* of the form :

Equation 2: State model

$$Y = a0 * (1- a1 * e^{(-a2 * P)})^{a3} \quad (2) \qquad \textit{State model}$$

The cumulative growth curve defined by this equation has a sigmoid shape and an upper asymptote; a0, a1, a2, and a3 are the four parameters (see Figure 4). The function gives the estimated forest area for a given population density level.

The following system of equations defines the model parameters:

$$(1) \quad a0 = YM$$

$$(2) \quad a1 = 1 - (Y0 / YM)^{(1 - b2)}$$

$$(3) \quad a2 = (1 - b2) * b1 * YM^{(b2 - 1)}$$

$$(4) \quad a3 = 1 / (1 - b2)$$

where YM = maximum possible non-forested area

Y0 = non-forested area for P = 0

b1 and b2 are parameters of the change model

It can be noticed that an additional variable Y0 is needed to solve the State model equation (2). Y0 represents the 'initial conditions' of the site, in terms of forest cover for population

density=0. The effect of different initial ecological conditions is illustrated in Fig. 4 where it was preferred to use forest cover on the Y-axis, rather than (100-forest cover) as in the original model formulation, but this has impact only on data presentation and the underlying conceptual structure remains unchanged. Moreover the three curves presented here are just theoretical examples and represent a simplification of the possible family of curves In practice each geographic unit can be represented by a different curve based on specific ecological conditions.

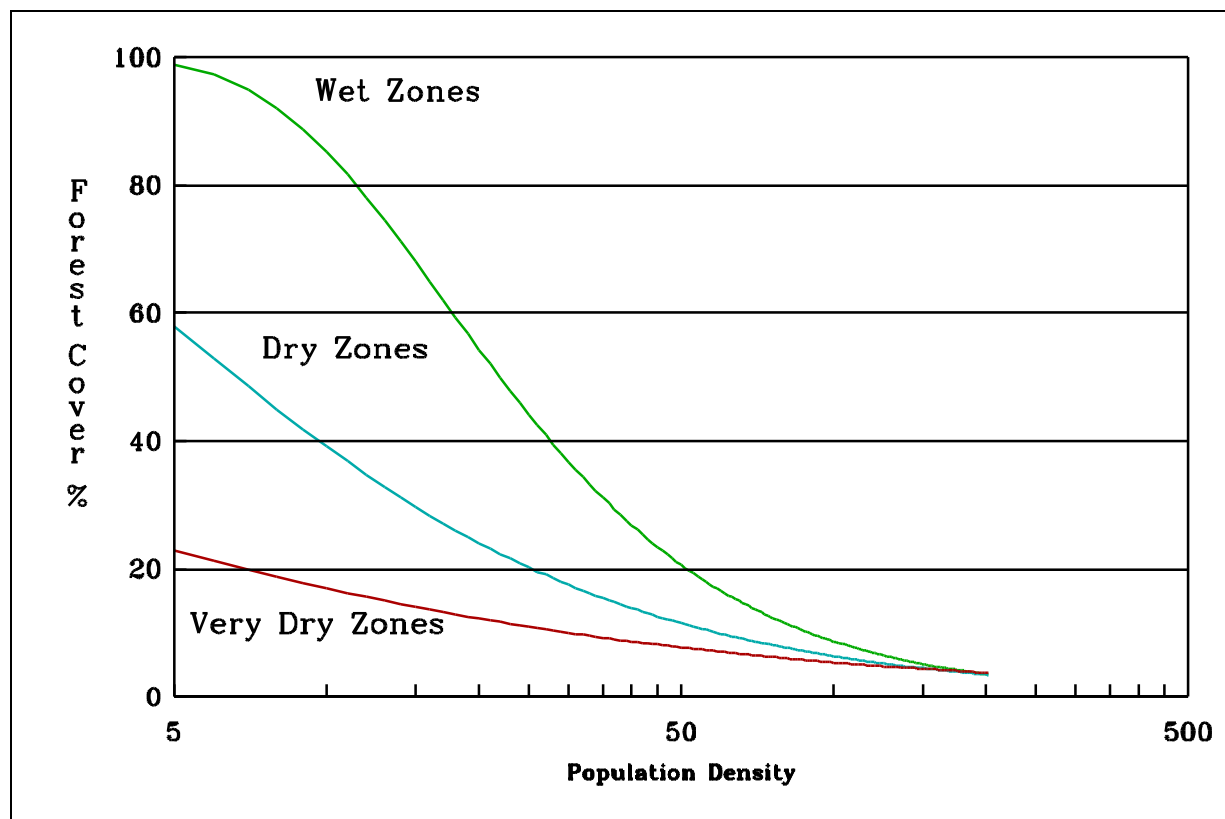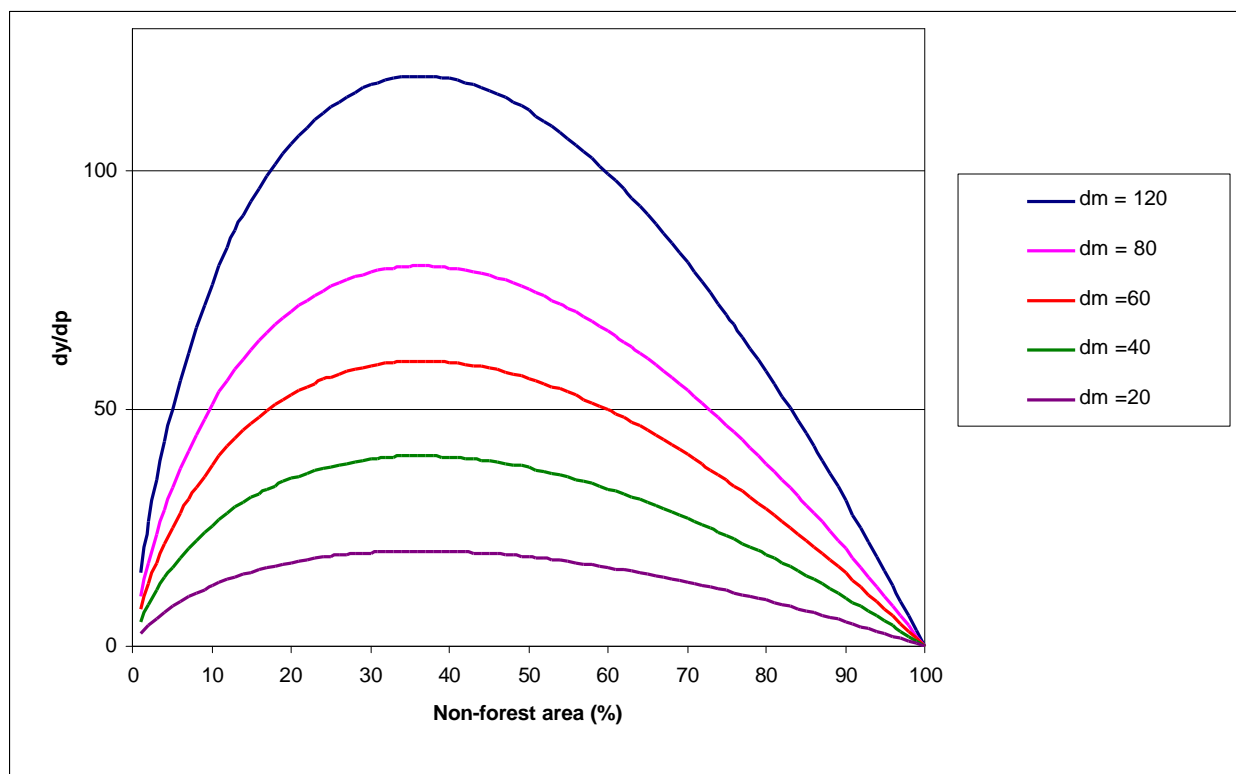**Figure 4: Illustration of model curves for different ecological zones**

Figure 5: Change model curves for different values of dm parameters

Model parameters values and influence of ecological zones

b2

From the statistical analysis it was found the b2 parameter was rather constant across different geographic regions and continents with a value of b2 = 0.98. It is reminded here that in the present model structure b2 represents the inflection point of the integral curve, corresponding to the non-forest percent value where the derivative reaches its maximum and the ratio dy/dp starts to decrease. Such value (b2 = 0.98) correspond to non-forest = 38% of maximum possible deforestation. No statistical evidence was found, given the data set used, of factors influencing b2, which is in practice considered as a constant in the present model formulation.

b3

b3 is function of Ym, the maximum possible deforestation. The derivative dy/dp when plotted against Y showed observations approaching zero forest change at various non-forest levels between 70 and 100%. However, the available series were too short and not sufficiently representative to enable precise estimations. Ym was then left at a constant 100% level in the general model. Estimates of Ym lower than 100% may be adopted locally for specific geographic units if local conditions suggest that for population growing to infinity deforestation will not reach 100% due to physical or legal constraints

b1

The output of the first step of the stepwise procedure, before entering the ecological variables to model, defines the raw average trend of the multi-data set, disregarding ecological parameters. In addition an attempt was made to verify, using statistical methods, the assumption that ecological conditions may have an influence on deforestation. In this case a stepwise statistical procedure was used to determine which ecological zones may influence dm parameter representing the maximum level of non-forest increase per unit population increase. Actually it was found that a combination of ecological zones (expressed as percentage of total land area) are significantly correlated to dm. The results of the statistical stepwise are as follows:

Equation 3: Estimation of dm from ecological zones

$$dm = 31.38 + 36.92 * E04 + 45.75 * E05 + 42.99 * E08$$

where E04 refers to the proportion of moist with long dry season zone, E05 to sub-dry zone and E08 to premontane moist zone.

Remarkably the findings above are significant not only from the statistical viewpoint but also conceptually. Moist with long dry season zone is perhaps the most favorable zone for agriculture expansion since it provides in tropical zones excellent conditions for crops and cattle raising, similarly sub-dry and premontane moist conditions are expected to follow the same pattern. Given the intrinsic approximation of a model of general nature as the one discussed here, such findings are considered interesting.

Local fit

As discussed earlier, the general model and its interpretation of the ecological components are meant to be valid at global level where local deviations are expected to balance at continental/global level.

However working at local level the model predictions should be calibrated keeping into account the specific socio-economic conditions.

For this purpose the model provides a specific procedure which was named 'local fit'. This estimation technique is based on a mathematical approach where once the general model parameters are known, dm (the derivative maximum) can be calculate as function of (dy, dp, y, ym, b2), using Equation 4.

Equation 5: Estimation of dm from local fit

$$dm \;=\; \frac{dy}{dp} \;*\; \frac{ym^{\,b2} \;*\; b2^{\frac{1}{(1-b2)}} \;*\; \left(\dfrac{1}{b2} - 1\right)}{y^{\,b2} \;-\; y \;*\; ym^{\,(b2-1)}}$$

This technique can be applied in units where at least two reliable estimates of forest cover in time are known. Such estimates are then used to compute observed dy. Using Equation 4 where in this case Ym and b2 are the general model parameters and dp, dy and Y are calculated from population growth and forest cover observed for the given unit, the local value of dm can be computed. Finally the local value of dm is substituted in the general model formula to estimate dy for a given dp.

Endnotes

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